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Report 1531-TR

MASS-FIRE CONTROL TEST

Project 8-76-04-214

25 June 1958

U. S. Army Engineer Research And Development Laboratories

ENGINEER RESEARCH & DEVELOPMENT LABORATORIES

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MASS-FIRE CONTROL TEST

Project 8-76-04-214

25 June 1958

Distributed by

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U. S. Army Engineer Research and Development Laboratories
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PREFACE

The tests covered in this report were conducted under the authority of subproject 8-76-04-214, "Atomic Fire Fighting Techniques and Equipment," 7 November 1952. A copy of the subproject card appears as Appendix A to this report.

Preparation for the tests and the conduct of the actual tests were performed as a troop endeavor by Companies C and B, respectively, of the 34th Engineer Battalion (C), Fort Lewis, Washington. Support was given by the Signal Corps Meteorological Team, Fort Hauchuca, Arizona; the Signal Corps Pictorial Service, Presidio, San Francisco, California; and the 33rd Transportation Helicopter Company, Fort Ord, California. Arrangements for the Military support were made through the Continental Army Command with the Sixth Army. The U. S. Forest Service California Forest and Range Experiment Station and the Shasta-Trinity National Forest Office assisted in local arrangements and technical problems. Key personnel of each organization are listed in Appendix B to this report.

The tests covered by this report were conducted from 4 to 12 October 1957.

CONTENTS

SUMMARY

The tests covered by this report were conducted to evaluate various items of equipment for use by untrained troops in fire-fighting operations. The tests were conducted by Engineer troops in the Trinity River basin of northern California.

Items tested were: quick-coupling tubing for emergency water-supply lines; in-line pump, which may be submersed to draft water to supply lines; hose lines laid by an H-21 helicopter; and protective clothing.

The report concludes that:

(a) The concept of assigning untrained troops to fire fighting is valid provided operational requirements are relatively simple.

b. A quick-coupling tubing system of the type used in the tests meets the requirements for a rapidly constructed emergency water-supply line.

c) Ground-air coordination for helicopter placing of hose and pump equipment as an emergency fire-fighting task force operation is feasible, provided certain refinements of equipment are accomplished. The submersible pump is suitable for use as a draft or booster pump in emergency water-supply lines.

d) The concept of convection water-fog generation for controlling large unconfined fires requires further development.

(e) The expendable aluminized-paper fire-fighter's ensemble can be used without prior instruction by field troops for protection against thermal radiation of large fires. Further development is required to improve durability of the garment.

MASS-FIRE CONTROL TEST

I. INTRODUCTION

1. Subject. This report covers tests conducted to evaluate various items of equipment and operational methods for troop use in effectively combating large fires. Equipment tested was an emergency pipeline and expendable aluminized fire fighter's ensembles; operational methods evaluated were placing a submersible pump and laying an expendable 8-inch hose using an H-21 helicopter; and comparing convected water-fog to straight water streams from deluge guns.

2. Background. The significance of fire as a weapon in modern warfare was clearly demonstrated in World War II. Even before the advent of nuclear weapons, the destruction effected by massed high-explosive and incendiary-bomb air raids on military and industrial concentrations was developed to an extent which was previously all but inconceivable. Eighty percent of the total damage in the great air raids on German cities in World War II was caused directly by fire. Fire storms, resulting from the coalescence of numerous fires over large areas, occurred in Hamburg, Kassel, Darmstadt, and Dresden. The effectiveness of fire is reflected in a fire storm of 24 July through 3 August 1943, in Hamburg, which completely burned out 12.5 square miles (32.5 square kilometers). The rush of air into the fire areas was reported to have attained velocities of 30 mph to over an estimated 125 mph (50 to 200 kmph), tossing fire fighters around and preventing them from coming within range of the fire with hose streams. This same incendiary technique was equally as effective as a destructive weapon in Japan during the air attacks of 9 and 10 March 1945 on Tokyo. There, the combination of dense population, heavily built-up combustible areas, ignition during a high wind, plus the element of surprise resulted in complete destruction of approximately 16 square miles (41.5 square kilometers) of the city and the death of 83,600 persons. This was perhaps the greatest loss of life by fire in the history of man. The nuclear bomb which exploded over Hiroshima killed almost as many and there, again, fire accounted for most of the damage.

The advent and development of guided [illegible] ballistic missiles makes the interception of fire-inciting weapons most difficult and has increased the probability of the planned delivery of such weapons at advanced base points by an enemy in the event of military operations. Large-scale destruction of military bases, supply depots, and points of embarkation is possible. Since these targets are of vital importance to military operations, means must be available to local military organizations to minimize the resultant fire damage. Since the Corps of Engineers has the responsibility of making

available the equipment and developing techniques for the Army which will afford maximum practical protection against fire, a study was initiated under subproject 8-76-04-214, "Atomic Fire Fighting Techniques and Equipment."

The magnitude of mass fires was investigated, and the need for special fire-fighting equipment was outlined.[1] Subsequently, contracts were let to develop special equipment -- a submersible pump, expendable lightweight 8-inch hose, and convection water-fog generator. The plans were to utilize the indraft of large-scale fires to carry the water particles into the base of the fire from the water-fog generator -- a technique which had been successfully demonstrated by other investigators on confined fires (inside a ship or building) but not on outside fires.[2,3] Completely self-contained groups of trained fire-fighters was envisioned, with these groups being augmented by large numbers of auxiliary fire-fighter troops who had received only rudimentary training in disaster operations. Consequently, the equipment and the techniques for use of the equipment would have to be of the simplest and most direct form for optimum application. Compatibility of troops with equipment and operating techniques was, therefore, a highly important factor requiring special study. Early troop evaluation of the equipment under conditions of similar use was deemed most desirable. In cooperation with the Continental Army Command, a test plan was set up as an Engineer troop-test operation.

Planning began in January 1956 with an investigation of possible fuels for the test fires. It was anticipated that the special equipment being procured under contract would be available by October 1957. To develop and prove the suitability of this equipment and the techniques for its use, large-scale fire tests were necessary. In order to assure valid interpretation of the results, the conditions should duplicate as nearly as possible the fire loading of a representative section of a military installation or an urban area and should exhibit a degree of homogeneity that could be easily reproduced. No built-up areas were found which could be fired to simulate a section of a mass fire. Other fuels, although not presenting the same configuration to a fire as a structure, could be used with knowledge of their limitations. The U. S.

1. ERDL Study Progress Report, Disaster Fire Fighting Techniques and Equipment, dated 1 July 1955.

2. Layman, Loyd, Attacking and Extinguishing Interior Fires, 1953.

3. U. S. Coast Guard, Reports of a Study of the Control and Extinguishment of Fuel Oil Fires in the Machinery Spaces of Vessels, 1 June 1945.

Forest Service suggested using unmerchantable timber in the western National Forest lands as fuel, and a survey was made with the cooperation of the U. S. Forest Service. First consideration was given to using logging slash;[4] however, the disadvantage to this material was that the density could not readily be determined nor could the fires produced from slash be duplicated with any degree of accuracy because of the random manner in which it was piled.

A more suitable fuel was found on the Stuart Fork of the Trinity River where there was a large quantity of standing unmerchantable timber which had to be cleared in an area to be inundated for a reservoir of the Trinity River Dam. The timber was uniformly small, making it appropriate for construction of multiple, identical log cribs to obtain any desired fire loading. A crib design was suggested by the U. S. Forest Service based on their fire test of various log crib configurations. Troops were made available by CONARC to cut the timber and construct the cribs in support of the test mission. The test site (part of the Cedar Stock Farm) was leased from the owners by the Corps of Engineers Sacramento District Engineer for a 5-month period beginning 1 July 1957. The lease covered logging the timber and use of the tract as a test site.

In planning the tests commencing in January of 1956, cognizance was given to the development of an apparatus to generate fine water fog which could be carried into fire by convection currents resulting from the fire.[5] Tests were conducted with a static fog generating device which indicated that quenching Class A fire cribs with airborne water drops was feasible. A contract was let to construct a field unit for fine water-fog generation, the unit to have the characteristics of mobility and satisfactory particle size for air current convection. The approach of the contractor in constructing a field device was, however, not conducive to completion of the contract work prior to the date of tests. A substitute item was required for use in troop tests, and a "breadboard" model, closely resembling the static device used in exploratory tests, was constructed in our shops. A nonclogging-type nozzle[6] which produced a fog approaching the fineness desired was selected for use in the field. Spacing of this type nozzle was made on a distribution grid

4. Logging slash is the unmerchantable material remaining after logging operations have been completed and consists of underbrush, tree tops and branches, and culled logs.

5. Layman, op. cit.

6. In this nozzle the fineness of the fog was not determined by the diameter of an orifice, but was produced by shearing thin sheets from a stream flowing through the nozzle body of comparatively large cross section.

such that coalescence of individual particles would be avoided in most part, which resulted in a lower density fog than appears ultimately desirable in this application. In view of the fact that a true prototype item was not available for testing at Trinity River, it was realized that results obtainable with the breadboard fog generator would be only of qualitative value in ultimate design of an actual item and not of conclusive nature in determining the merit of a fully engineered device.

Another item, the two-wheel trailer, originally included in the scheduled test program was not completed by the fabricator prior to the test date. This trailer carried the lightweight, 60-kw, 60-cycle, gasoline-engine-driven generator unit, and incorporated carry-space for the submersible pump. Since this item was not available for the test program, it was necessary to substitute the skid mounted, continuous service, 60-kw generator which is an item of issue. For this reason, evaluation of pump and power supply as a unit could not be made.

All the equipment to be tested and equipment for support of the test were shipped from the eastern seaboard to the test site. One submersible pump and three deluge guns were mislaid in shipment and did not arrive until after the tests were completed, necessitating deletion of the commercial fog nozzle test and operating of the fire-fighting equipment at a lower pressure for the other tests. In addition to these deterents, unprecedented prolonged rains occurred for several weeks prior to the test and continued throughout the test week. The wood cribs and kindling fuel were wetted despite the waterproof barrier materials with which the cribs had been covered earlier.

II. INVESTIGATION

3. Description of Test Items. The test area was located in the Weaverville Ranger District of the Shasta-Trinity National Forest, 72 road-miles northwest of Redding, California (Fig. 1). The test area was meadowland about 3/5 mile wide by 3 miles long at an average elevation of 2150 feet, with hills on either side rising to 3350 feet. A description of the items tested follows.

a. Submersible Pump. The prototype pump is a portable unit consisting of a single-stage centrifugal pump element assembled on a rotor shaft of an oil-filled submersible motor. The unit may be carried manually to the pumping site where the suction strainer, discharge piping, and power cable are installed before the unit is lowered into a lake or river. The unit can also be used as a booster pump in a pipeline with other units connected in series. The operating characteristics are as follows:

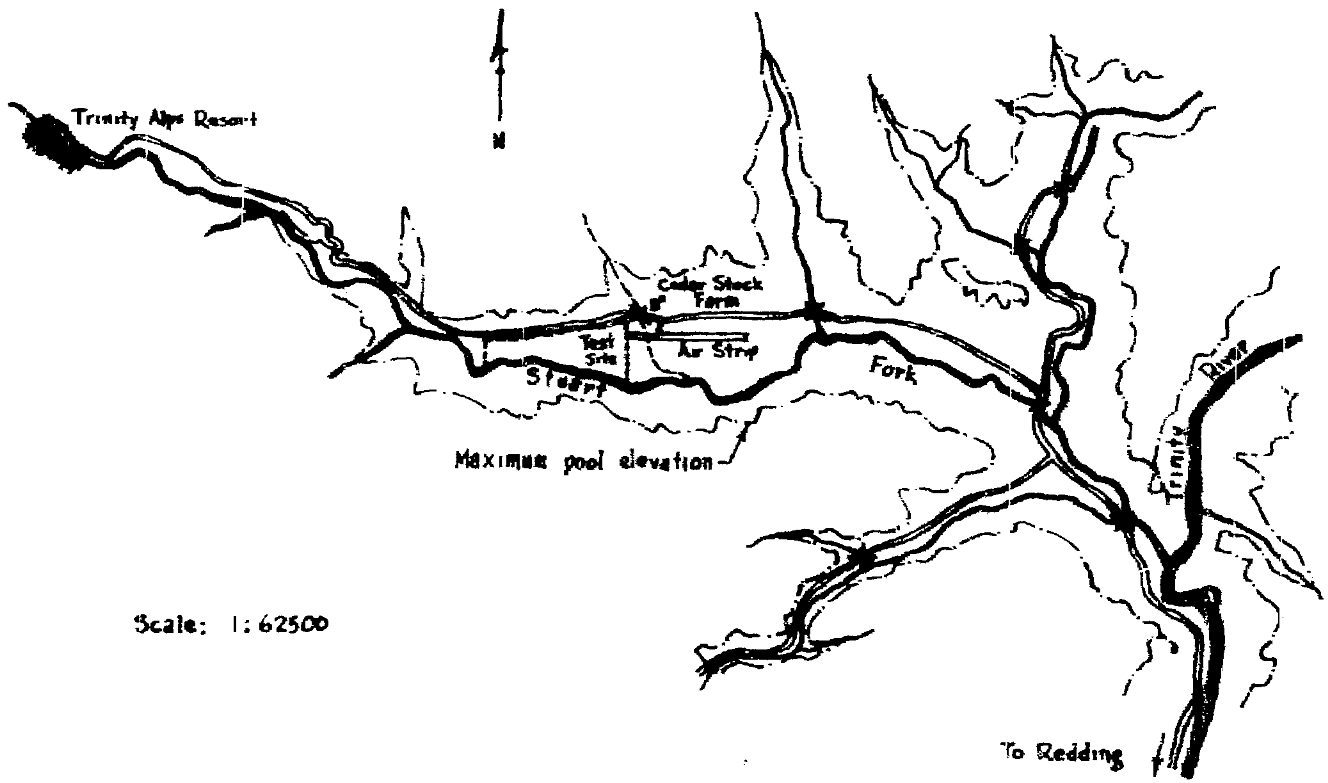


Fig. 1. Test Area, Stuart Fork
Shasta-Trinity National Forest, California.

Capacity, Rated	1500 gpm (5675 lpm)
Total Dynamic Head	120 ft (2.5 kg per sq cm)
Suction Pressure	Atmospheric
Pump Speed	3525 rpm
Weight	503 lb (228 kg)
Electrical Requirements	60 kw, 440 v, 3 phase, 60 cycles

Power for the pump is provided by a special, lightweight, trailer-mounted, electric generator. The trailer also carries the pump, suction hose, and electric cable. A hoist is provided to lower the pump into the water.

b. Quick-Coupling Tubing. The tubing is a commercial 8-inch irrigation-type piping made by the W. R. Ames Company. The physical characteristics of the tubing are as follows:

Diameter	8 in. (20.3 cm)
Length	20 ft (6.1 m)
Weight	84 lb (38.1 kg)
Working Pressure	154 psi (10.8 kg per sq cm)

The couplers are the galvanized steel ball-and-bell type. Sealing is accomplished by a compression gasket. The pipe is coupled by inserting the ball end of one piece into the bell end of the preceding piece until the ball is caught by a coil spring within the bell.

c. Expendable 8-Inch Hose. The 8-inch hose is an experimental lightweight hose designed to be laid from trucks or helicopters for emergency water-supply lines. The hose is packed serpentine-fashion in 500-foot lengths in an open box, and the boxes may be stacked and the hoses joined into a continuous length. Physical characteristics are as follows:

Diameter, inside (hose)	8 in. (20.3 cm)
Construction (hose)	1/16 in. (1.59 mm) calendered natural rubber tube, 2 plys of nylon cord fabric, 3/64 in. (1.19 mm) calendered natural rubber cover
Weight (hose) (exclusive of couplings)	2.3 lb per ft (3.42 kg per cm)
Weight (couplings) (per pair)	87 lb (30.4 kg)
Working pressure	50 psi (3.5 kg per cm^2)
Flaking box	
Weight	278 lb (126 kg)
Construction	Fiberglas and steel
Weight (sling)	60 lb (27.2 kg)

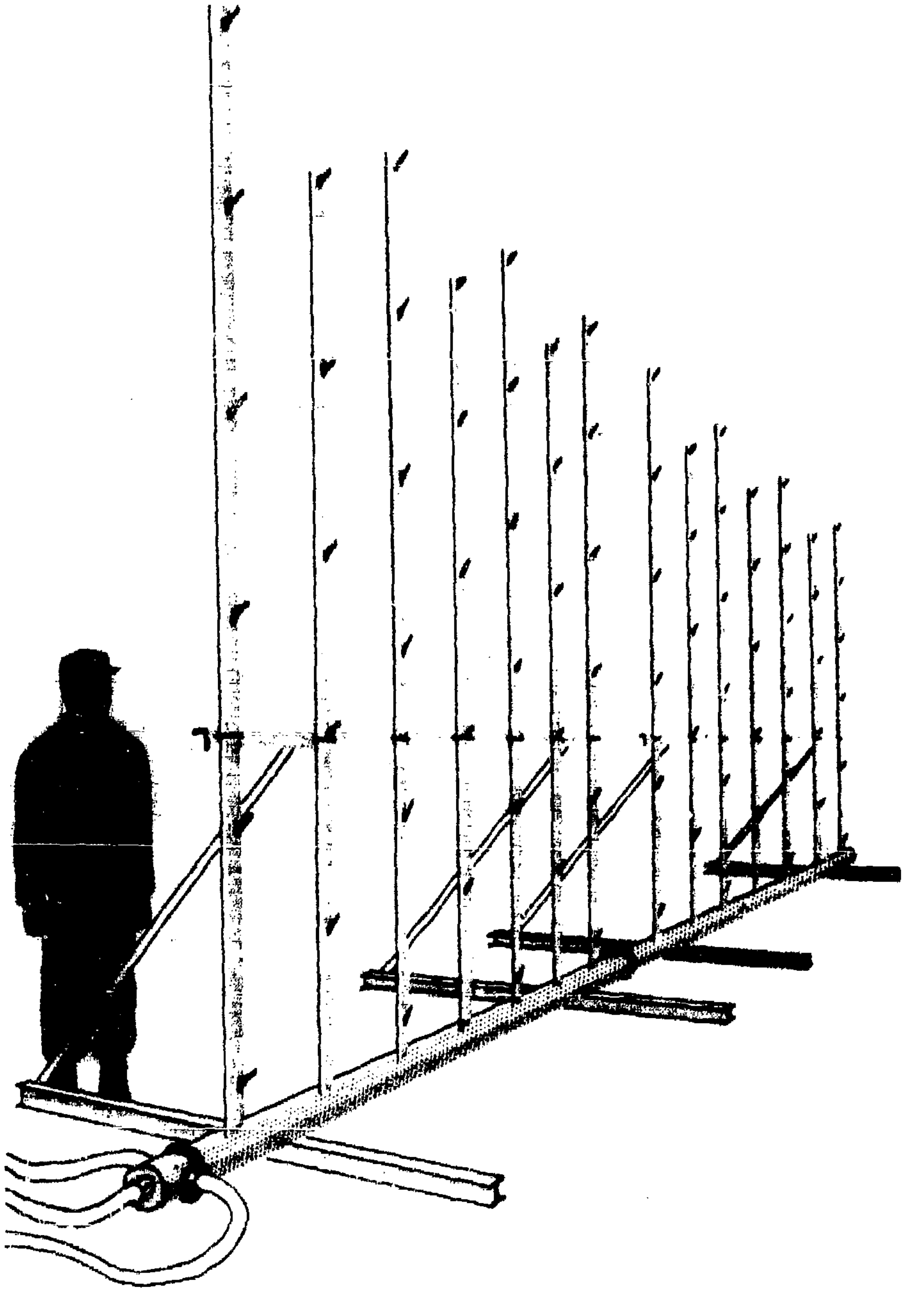


Fig. 2. One section of the breadboard-model water-fog generator.

d. Fog Generator. The fog generator used in the test was the breadboard model fabricated in the USAERDL Shops. It consisted of two sections, each 40 feet long (Fig. 2). The base of each section was made of two 20-foot lengths of 6-inch steel pipe coupled in line, using standard POL grooved pipe couplings. Fourteen vertical 2½-inch standpipes were welded into each section. Six standpipes were 15 feet high, and eight were 17 feet high. Five Bete Model B12FC (full cone) non-clogging fog nozzles, inclined 45° upward, were attached at 3-foot intervals on each of the shorter standpipes, and six nozzles were installed at the same angle and spacing on each of the longer standpipes. Vertical stability was provided by horizontal supports welded to the 6-inch pipe base and braced to an angle-iron spacer attached horizontally to the standpipes approximately 6 feet above the base. The adjacent ends of the two groups were connected to the feed line through two adapters to six 2½-inch hose lines. The output of the complete unit is shown in Fig. 3.

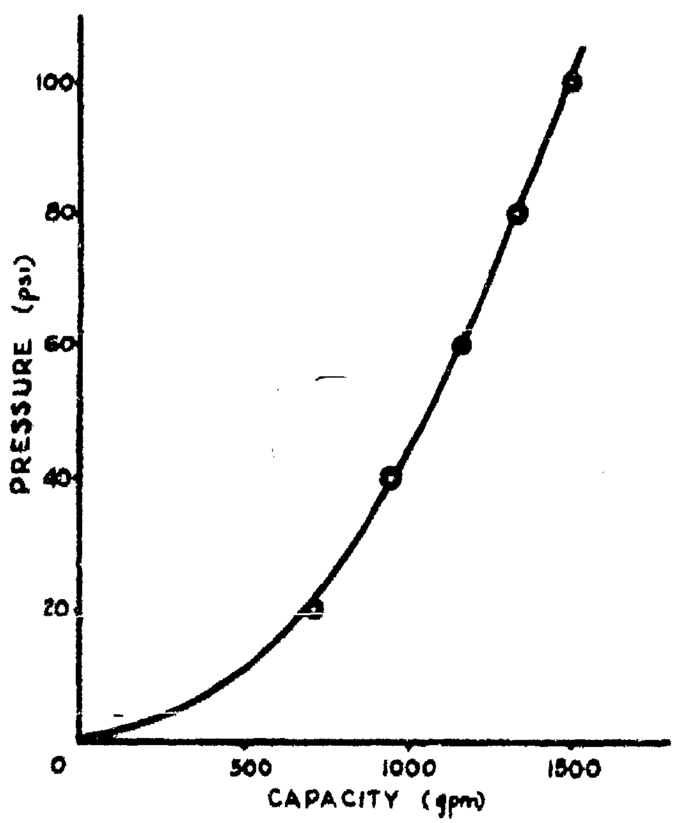


Fig. 3. Capacity of breadboard-model fog generator.

e. Quartermaster Experimental Fire-Fighting Protective Clothing Ensembles. Four different ensembles were received from the Quartermaster Corps for testing in fire fighting. Following is a brief description of each.

(1) Expendable, Aluminized-Paper, Fire-Fighter's Ensemble. This ensemble was designed to provide optimum protection against thermal radiation for troops engaged in emergency fire fighting. The ensemble is fabricated of aluminized, laminated, kraft paper which had been creped for pliability and treated for flame resistance. It consists of the following components.

(a) Parka with attached hood. The parka is designed basically on the lines of an Arctic parka, with long sleeves and adjustable sleeve closures. The attached hood is provided with an overlapping chin closure and drawstrings. The parka is sized to wear over a duty uniform and designed to permit a breathing apparatus (Chemox) to be worn underneath. The hood is sized to fit over a steel helmet.

(b) Leg sleeves. The leg sleeves, with adjustable closures, are designed to protect the lower extremities. They extend up to the crotch and are held in place by adjustable straps which are hooked to the belt of the duty uniform.

(c) Face mask. The face mask is designed to underlap the hood and is constructed so that it is held away from the face. The eye openings are a pattern of punched holes.

(d) Mittens. The mittens are the gauntlet type with fabric palms slit to permit the wearer's fingers to be extended for dexterity without removing the mitten. The back of the mittens is insulated with three layers of corrugated embossed paper placed between two layers of base material to eliminate the need for a liner.

(2) Experimental Aluminized Fire-Fighter's Ensemble. This ensemble consists of aluminized neoprene-coated standard fireman's coat and bunking trousers.

(3) Integrated Protective Ensemble. This ensemble consists of an experimental all-purpose, protective, integrated coat and trousers. It is fabricated of impregnated cotton cloth.

(4) Thermal Radiation Suit. This suit is of Swedish make and consists of a coat, hood, trousers, boots, and mittens of aluminized fiberglas fabric and is intended for use as a fire entry suit.

f. Deluge Guns. The deluge guns are standard Civil Defense models (three 2½-inch inlets and one 2½-inch outlet with 1¼-, 1-3/8, and 1½-inch stacked tips).

g. Pumper. The pumper, loaned by the Weaverville Fire Department, is rated at 1000 gpm at 150 psi and conforms to the specifications of the California Disaster Office.

4. Support Equipment, Instrumentation, and Personnel. The troop operations were in two phases: the first, preparing the test area; and the second, conducting the technical tests. Equipment in addition to that authorized by the TO&E for the troop unit and the phase in which it was used is shown in Table I.

Table I. Support Equipment and Phase in which Used

Item of Equipment	Quantity	
	Phase 1	Phase 2
Wrecker	1	1
Water Purification Equipment Set	1	1
Portable Chain Saw, GED	20	0
Tractor, D-7, with Angledozer	2	1
Semitrailer, 20-ton, low-bed	2	1
Helicopter, H-21	0	2
Generator, Engine, 60-kw	0	5
Miscellaneous Hose and Pipeline Accessories		

Quartermaster paper thermal indicators which change color from white to black at five temperatures between 169 and 493 F (76 and 256 C) were used to measure the radiant heat and transmitted heat on the QM clothing tested. Meteorological equipment which was used in the test is described in the U. S. Electronic Proving Ground Report, "Meteorological Summary for Mass-Fire Control Test," included as Appendix C. Key personnel who assisted with the tests are listed in Appendix B.

5. Test Preparation. In June 1957, Company C, 34th Engineer Battalion (C) of Fort Lewis, Washington, consisting of 3 officers and 120 enlisted men, arrived at the site to start preparations for the test. The fir and pine timber was cut and trimmed into 13,000 logs, and the cribs were constructed (see Fig. 4). The cribs were

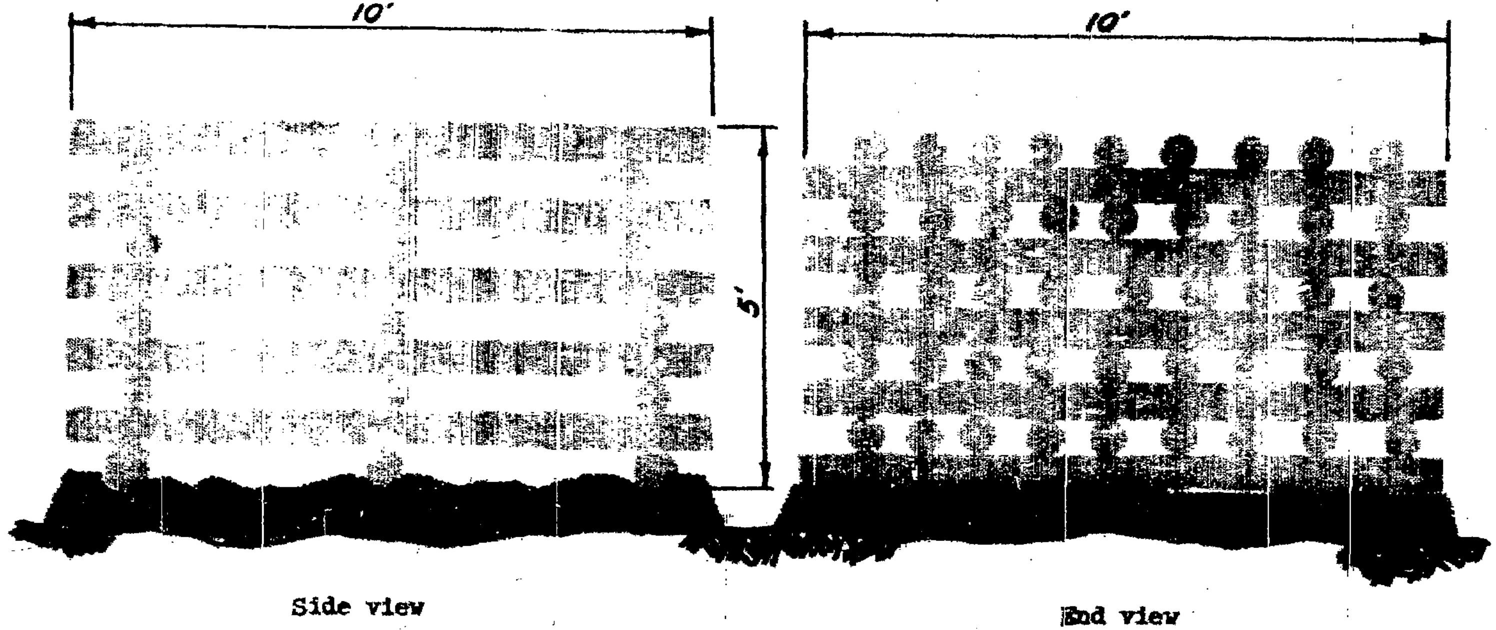


Fig. 4. Basic log crib. Material: Sixty 10-ft logs, 3- to 9-in. diameter, dead or 4-month air-dried fir or pine, on 8-in. loose pack of branches and tree tops.

arranged in 4 groups of 52 cribs each, laid out in 4 rows with the cribs spaced at 2½-foot intervals. (After completion of the first fire test, three of the groups were rearranged as discussed in paragraph 6d.) In mid-September, the cribs were covered by the U. S. Forest Service with waterproof barrier material to protect them from dampening by the first fall rain.

6. Test Procedure. The second phase of the operation was conducted between 4 and 12 October 1957 by Company B, 34th Engineer Battalion (C), Fort Lewis, Washington, and consisted of conducting the tests described in the following paragraphs.

a. Quick-Coupling, 8-inch Tubing, with Ball-and-Bell Couplers. The purpose of this test was to evaluate the suitability for troop use of the emergency pipeline and to determine the maximum coupling rate, the optimum size of a pipe-coupling crew, and the effect of previous coupling experience. The pipe was carried to the test site on a pole trailer with alternate pipe sections reversed because of the larger coupler (bell) on one end. The pipe was then unloaded by the troops from the moving trailer and placed, uncoupled, end to end along the shoulder of a level road. A preliminary study indicated that only two men were required to couple the pipe; one man to guide the ball coupler into the bell coupler of the preceding pipe section, and the second man at the other end to push the pipe into position. This basic crew, and variations of it, were timed as they coupled 1000 feet (49 joints) of pipe. The pipeline was tested to the full rating of the pumps [1500 gpm (5675 lpm) at 80-foot head (2.5 kg/cm^2)].

b. Helicopter Pump-Placing and Hose-Laying Tests. These tests were conducted to determine the feasibility of using an H-21 helicopter for (1) placing a submersible pump in an otherwise inaccessible water source, and (2) laying an expendable 8-inch hose over terrain impassable to vehicles. A simulated inaccessible water point had been chosen with sufficient clear area for helicopter operation. A nearby grove of trees was the "impassable terrain."

Two helicopters were used. The first helicopter deposited a box of hose on the bank near the water point, where it and the electric cable were assembled to the pump. The pump was then picked up and carried about 30 feet out over the deepest water and released from a height about 2 feet above the water. The helicopter then picked up the hose box with the remaining hose and flew over a row of trees (the "impassable terrain") flaking out the hose as it proceeded. The second helicopter hovered on the opposite side of the trees while ground personnel unflaked and dragged approximately a hundred feet of hose over to the end of the first length of hose and coupled the two. The second helicopter ascended vertically to clear the trees before beginning forward flight.

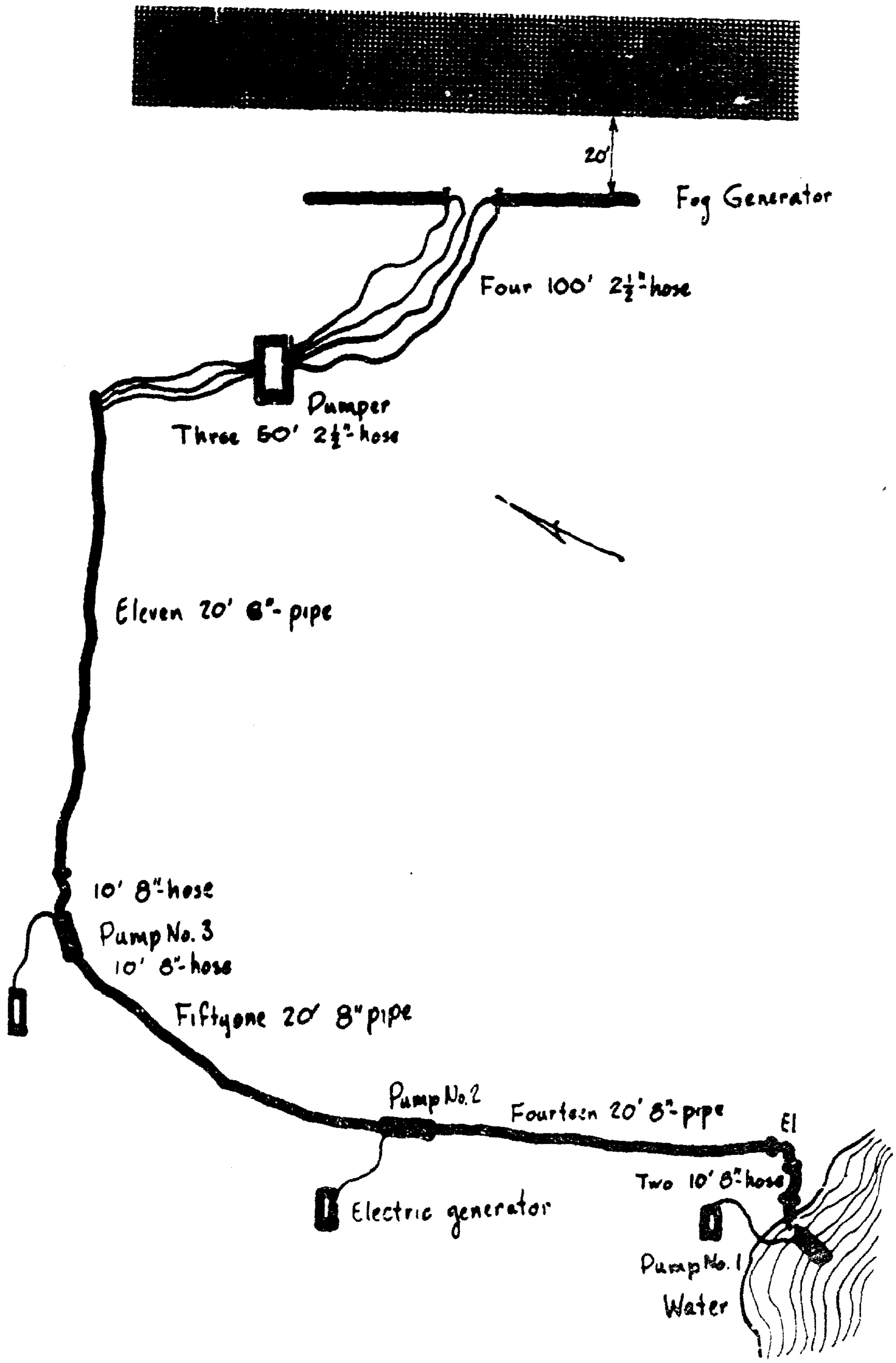


Fig. 5. Setup for Fire Test No. 1.

c. <u>Fire Test No. 1</u>. The first fire test was conducted to evaluate the characteristics concerning application of a very fine water fog to a large-scale, unconfined fire. The breadboard-model convection water-fog generator was set up 20 feet from and parallel to the west side of one of the crib groups. The 8-inch pipeline extended from the water point in the Stuart Fork to the fog generator (Fig. 5).

The weather was overcast with intermittent light rain, and since the long-range forecast predicted no break in the weather, it was decided to go ahead with the test. The wind was variable and low in velocity and the rain continued throughout the test. Four hundred gallons of diesel oil and gasoline in a 1:1.2 mixture were poured along the back side (the side away from the fog generator) and the ends of the crib group to assist ignition. The crib group was fired at 1527 PST. The cribs burned slowly due to the moisture in the kindling fuels and the logs. Water moisture content in the logs sampled was over 100 percent. The cribs were bulldozed into a more compact mass to aid combustion.

After 40 minutes of burning, the fog generator was employed. Water output was approximately 860 gpm at 95 to 100 psi pressure measured at the third pump. Pressure differential across the pump was 45 psi. After the fire was controlled, the fog was stopped and the fire allowed to burn out.

d. <u>Fire Test No. 2</u>. The object of this test was the same as Fire Test No. 1. Concurrent with this test and Fire Tests 3 and 4, Quartermaster clothing tests were also run. The fog generator was relocated in front of a new crib group in the same manner as for the first fire test. The 8-inch pipe was reassembled as shown in Fig. 6. As a result of the first fire test, the remaining crib groups were modified to present a more consolidated fuel. The outer rows of cribs were staggered atop the two inside rows. The top cribs were more dense and were not piled in any definite pattern (Fig. 7). The crib groups were 15 logs high, or about 8 to 10 feet. Twenty-six worn out tires were cut in half and arranged beneath the cribs in each group to act as a receptacle for the gasoline-oil mixture. A 610-gallon diesel oil and gasoline (1:1.1) mixture was distributed completely around the crib group, and ignited in midmorning. The cribs burned unevenly and slowly. The voltage regulator failed on the standard engine generator supplying power to the first (draft) submersible pump, preventing water from being pumped to the fog generator for the test. The fire burned itself out.

A break in the previous foul-weather period occurred about 0900 hours on the day of this test with the overcast beginning to clear. It was decided to take advantage of this first clear day, and arrangements were made to burn the remaining two crib groups that afternoon.

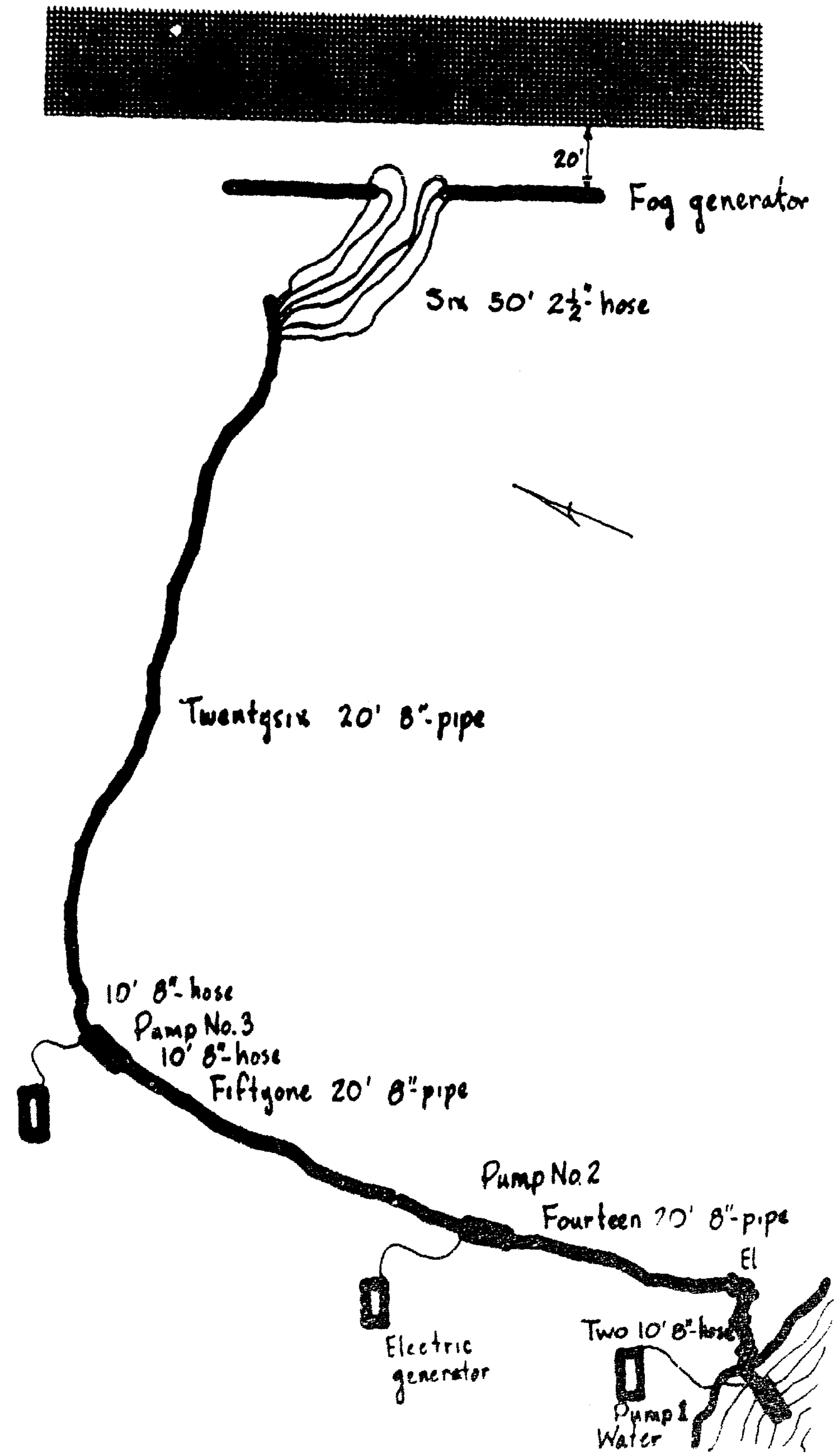


Fig. 5. Setup for Fire Test No. 2.

Fig. 7. Consolidated crib group.

e. Fire Test No. 3. The objective of this test was to note the effectiveness on a fire of straight streams from deluge guns, in order to compare with the fog generator using the same quantities of water on the other fires.

Two Civil Defense model deluge guns with $1\frac{1}{2}$-inch tips were set up 30 feet apart and 125 feet from the west side of the third crib group. The 8-inch pipeline was reassembled as shown in Fig. 8. Twenty-six halved tires were arranged among the kindling fuel and a 600-gallon diesel oil and gasoline (1:1.4) mixture was poured around the cribs to aid ignition.

The cribs were ignited in the early afternoon of the same day. The fire was uneven but of fair intensity. Water was applied from the deluge guns.

f. Fire Test No. 4. The objective of this test was to evaluate the characteristics concerning the application of very fine water fog to a large-scale unconfined fire, as in Fire Tests Nos. 1 and 2. The water-fog generator used in the previous tests was relocated 20 feet from and parallel to the east side of the fourth crib group. The east side was chosen for this test since the U. S. Forest Service desired an unobstructed view of the fire for thermal radiation measurements which had to be from the west to avoid sunlight interference. An immediate weather forecast indicated that the south wind might shift to either the southeast or southwest quadrant, so the generator was set up near the southeast

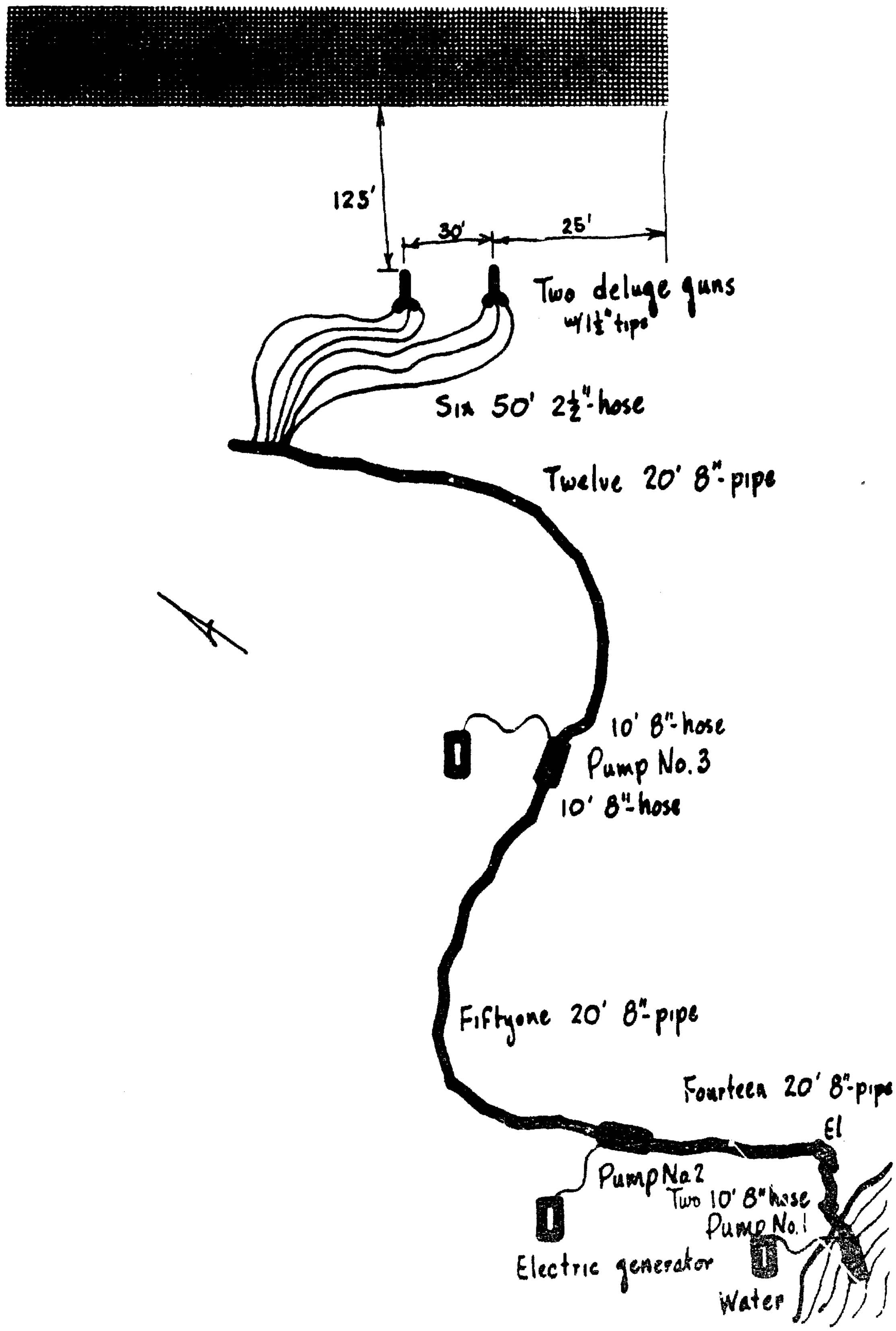


Fig. 8. Setup for Fire Test No. 3.

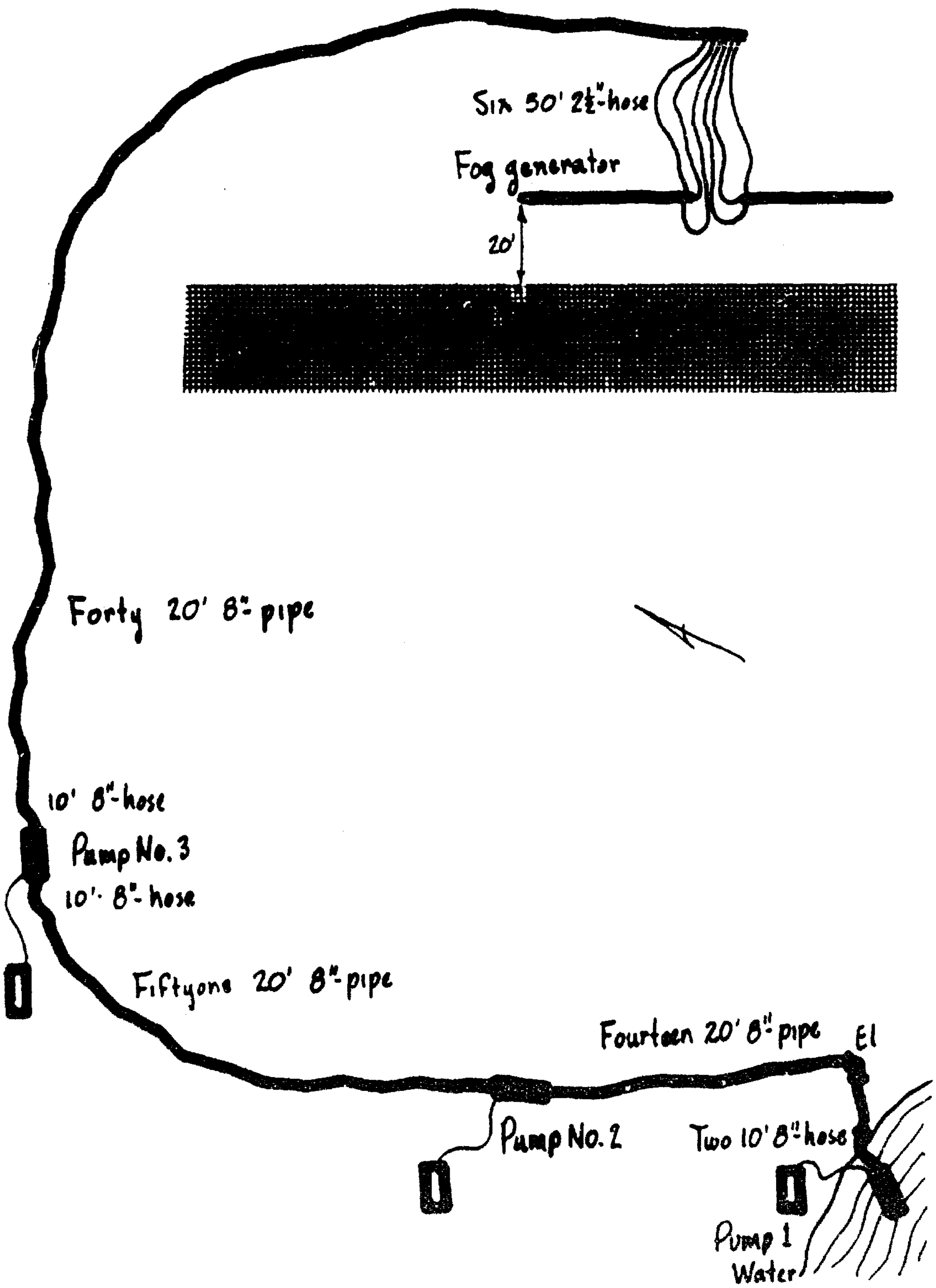


Fig. 9. Setup for Fire Test No. 4.

Fig. 10. Test Fire No. 4 at maximum intensity.

corner of the crib group. The 8-inch pipeline was reassembled as shown in Fig. 9. Halved tires and a 700-gallon diesel oil and gasoline (1:1.5) mixture were added as before to the crib group, and the cribs were fired at 1640 hours PST. Fig. 10 shows the fire at maximum intensity.

Meteorological equipment was set up to measure the effect of the fire upon ambient conditions and especially to measure the magnitude of the indrafts to the fire. The instruments were oriented along a line perpendicular to the long axis of the crib group from the midpoint. Ambient free-air temperature and relative humidity, surface wind speed and direction, and upper wind speed and direction data were taken. This data is detailed in Appendix C.

g. Protective Clothing Tests. The clothing ensembles tested in Fire Tests 2, 3, and 4 were as described in paragraph 3e, plus utility clothing such as cotton shirt and trousers (OD-107), helmet liner, cotton undergarments, etc. An array of QM paper thermal indicators were attached to the inside and outside of the ensembles prior to the start of the tests. The troops moved slowly toward the fire until their maximum endurance to heat was reached and then withdrew. The minimum distance from the fire and the maximum temperature attained were recorded, while comments were elicited from the troops.

7. Test Results. Results of the tests conducted are described in the following paragraphs.

a. Quick-Coupling, 8-Inch Tubing Test Results. Three-hundred feet of pipe (15 sections) were unloaded and placed end to end by a crew of 6 men in 2 minutes and 35 seconds. Two men pushed the pipe off the end of the pole trailer while four men pulled and placed the pipe. The results of the coupling test are shown in Table II.

Table II. Pipe Coupling Rates of Various Sized Crews

Crew Size	Coupling Rates (minutes-seconds per 1,000 feet) Inexperienced Crew	Experienced Crew
One 2-man crew	5:25	Not performed
Two 2-man leap-frogging crews	3:25	3:33*
One 3-man leap-frogging crew	3:55	Not performed
One 4-man leap-frogging crew	3:15	3:15

* Men were tired from previous trial

Of the crews tested, a four-man crew was the fastest, coupling 1000 feet of prelaid 8-inch pipe in 3¼ minutes. The crew had no prior experience in coupling this pipe, but the members were used to working with each other. No increase in speed was achieved with an experienced crew.

With pressure at full rating of the pumps, the first (draft) pump uncoupled from the 10-foot length of 8-inch hard hose and the el, tees, and plug uncoupled from the pipe. This was expediently corrected by tying recoupled pieces together.

b. Helicopter Pump-Placing and Hose-Laying Test Results. When the first helicopter ascended to clear the trees, an excessive amount of hose flaked out. As the hose descended, it hung in the trees but the heavy coupling on the free end fell to the ground. An excessive amount of hose flaked out from the second helicopter also when in vertical ascent, and the end was reached before the helicopter was above the trees. The 800 feet of hose filled slowly because of the many folds deposited on the ground when the helicopter ascended vertically and the restrictions where the hose was caught in the crotches of the trees. As the water was pumped into the hose, the weight and pressure of the water broke off branches as large as 3½ inches in diameter, causing the hose to fall until caught in larger crotches. The flow was restricted to an estimated 30 to 50 percent

of the rated capacity of 1500 gpm. There was no apparent damage to the hose.

c. Fire Test No. 1 Results. In this first fire test, the fire was controlled along the 100-foot front facing the fog generator within five minutes, although a significant portion of the water fog fell out before reaching the fire while small amounts were convected upward or through the fire. About one-third of the Bete nozzles were clogged with grass, twigs, and sand. The large size of most of the particulate matter was due to the rain-swollen condition of the Stuart Fork.

d. Fire Test No. 2 Results. As a result of the voltage regulator failure and the subsequent inability to pump water to the fog generator for the test, no results were obtained.

e. Fire Test No. 3 Results. The fire was controlled within 2 minutes over the entire front by operation of the deluge guns. Approximately 1200 gpm were discharged by the two guns.

f. Fire Test No. 4 Results. During the fueling operation for the fourth fire test, the low angle of the sun caused a cooling of the air on the shaded mountain slopes above the test site inciting a gravity-type wind (from west to east) in the test area which overcame the local south wind. Gasoline vapors accumulated in the lee of the crib and spread the fire to the grass. A misinterpretation of signals delayed the water delivery which resulted in exposure of the hoselines (which supplied water to the fog generator) to the grass fire resulting in destruction of three of the six hoses and the subsequent loss of pressure and water.

At this time, the wind speed increased nearly threefold (max. 18 mph) on the leeward side of the cribs without any corresponding change on the windward side. The high wind offset the possibility of forming a typical convection-type cell with corresponding indrafts from the leeward side. As a result, none of the water-fog reached the fire. By 1740 hours (one hour after the fire was started) the flames were no longer the dominant feature of the fire which quickly reduced to embers. The bed of live coals continued to give off significant amounts of heat beyond 1800 hours. Also, a pronounced change in the direction of the wind to the north occurred on the leeward side. By 1750 hours the gravity-type wind had slowed down sufficiently to permit the induction of a convective-type cell over the bed of coals and thereafter the wind recorded on the east side of the fire began to flow into the fire and oppose the natural circulation on the west side. This was marked by a shift of the west wind to the south, creating a counter-clockwise rotation of the air currents above the bed of coals.

Table III. Protective Clothing Test Results

Ensemble	Fire No.	Number of Test Subjects	Minimum Distance from Fire (ft)	Maximum Radiant Temp. Endured (°F)**	Remarks
Expendable Aluminized Paper Fire Fighter's Ensemble	2	22	1*	400	Hoods were not closed properly. Six subjects complained of heat on neck, 4 on forehead, 8 on hands, and 4 on feet.
	3	22	1*	400 plus	One subject complained of heat on forehead, 1 on hands, and majority on feet. Ensemble tore easily when wet; helmet liner edge cut hood where contacted.
Experimental Aluminized Fire Fighter's Ensemble	2	1	10	300	Limit was impaired by lack of protection for hands and face.
	3	1	not known	400	With aluminized paper mask and mittens.
Integrated Protective Ensemble	2	1	10	300	Limit was impaired by lack of protection for hands and face.
Swedish Thermal Radiation Suit	3	1***	10	490 200 (inside)	
	4	1***	4	500 150 (inside)	Lining was charred in several places. Face piece discolored yellow.

* For periods of 2 to 3 minutes.
** Measured by paper thermal indicators taped on outside of ensemble.
*** Displayed on wood framework.

g. The results of the protective clothing tests are summarized in Table III.

III. DISCUSSION

8. General Discussion. During a period of several weeks prior to the tests, the weather for northern California was characterized by a series of low-pressure areas moving in from the west with attending abundant rainfall. Weather for the month of October usually consists of a large percentage of sunshine with about 5 days of rainfall averaging about a hundredth of an inch. The departure from normal conditions experienced prior to the test has a probable occurrence of about once in 80 years. The frequent occurrence of rain and the nearly continuous cloud cover resulted in maximum saturation of the exposed logs and ground, with virtually no opportunity for drying periods.

Troops responded well in using emergency fire-fighting equipment in operational situations, even though they had received minimum instructions. No difficulties were experienced with either the hose, pipe, or expendable fire-fighting ensemble. Although operation of the standard 60-kw generators proved somewhat troublesome, no difficulties should be encountered with the simplified controls of the special generator which will be part of the submersible pump set. The concept of assigning troops to fire fighting as a secondary mission (i.e., one other than that for which they have been trained) is valid provided that the equipment operation is no more complex than that of automotive equipment.

The grouped log cribs provided an economical and easily constructed fuel unit. Any number of similar crib groups can be built with the assurance that the parameters of combustion will remain substantially constant from one fire to another which will permit direct comparisons. The cribs used in these fire tests were especially vulnerable to the weather because of their openness. The precautions taken to protect them from expected rainfall were inadequate against the adverse weather that did occur. As a result, the crib groups burned poorly despite efforts to aid combustion by consolidating the cribs in each group and adding tires, gasoline, and diesel oil. Insufficient indrafts were created by these fires; however, it appeared that the crib fires were not of sufficient magnitude, even if burned with the fuel dry, to generate indrafts capable of convecting requisite quantities of water fog for rapid control of the fire and to permit exploitation of this technique.

9. Analysis of Test Results. Following is an analysis of the test results.

a. Quick-Coupling, 8-Inch Tubing. The pipeline tests showed that irrigation-type 8-inch tubing with Ames couplers can be assembled into a pipeline by inexperienced field troops at a rate of approximately 3½ mph per 1000 feet, although the rate would probably drop to 2 mph for a sustained distance. Some difficulty was encountered in maintaining a coupled line under 80 psi pressure where it was not restrained by rigid pipe lengths. Terminal fittings, els, and pipe-to-hose adapters with Ames couplers required tying to the rigid pipe to prevent uncoupling. The pipe unloading rate was lower than the estimated sustained coupling rate indicating a need for a study of unloading techniques and possible equipment required to produce an unloading rate compatible with the coupling rate.

The prototype submersible pumps worked very well in the pipeline both at draft and as booster pumps. The unavailability of the special, lightweight, engine-generator sets for the pumps required expedient wiring to the standard 60-kw engine generator sets for power. Mechanical and electrical troubles were experienced with the rebuilt generators. Failure of the voltage regulator occurring at the beginning of Fire Test No. 3 prevented water from being pumped with the subsequent loss of the opportunity to conduct the test. Unsatisfactory Equipment Reports were submitted on this equipment.

b. Helicopter Pump-Placing and Hose-Laying Tests. The use of the helicopters was seriously curtailed by the adverse weather. The tests, though limited, showed the basic feasibility of employing helicopters to lay emergency water-supply lines (using submersible pumps and 8-inch hose) over areas inaccessible to vehicles. Certain problems were also brought out.

When the laying helicopter was ascending, a critical altitude was soon reached where the weight of hose in suspension between the flaking box and ground was equal to the force required to flake out the hose. When the hose is contained in the box without restraint, this critical altitude is quite low; surplus amounts of hose flake out, reducing the effective water transport range of the hose length and restricting the flow of water through the hose because of twists and kinks. The critical altitude for this particular hose was between 50 and 100 feet. A serious operating restriction is imposed when there are ground obstructions which the helicopter must clear to complete a hose-laying operation. In analyzing the test results, it appears that these difficulties can be eliminated by employing a method of operational restraint at the flaking box to control the rate of hose flaked from it, regardless of the altitude or movement of the helicopter.

Severe kinking occurred in a few places where the hose was deeply draped through tree crotches. Where this occurs,

it may be necessary for ground teams to cut the branches and clear the more severe kinks. Additional tests over various types of wooded terrain are necessary to determine the extent of study required on this problem. Advantages gained in speed of laying and high capacity will be partially offset until these restrictions are cleared. Nevertheless, in an emergency such as immediately after a nuclear weapon attack, this method could be used to expeditiously provide water over debris-choked or otherwise impassable areas, using a minimum of personnel to lay the hose. Operating personnel would be protected from residual radiation by the height of the helicopter above the contaminated area except when the helicopter descended to allow the personnel to couple the hose to the preceding length.

The experimental 8-inch hose was considered too heavy for helicopter hose-laying operations (1000 feet maximum can be carried per helicopter), but the tests were undertaken for the value to be derived from a troop-use test before conducting further investigation into lighter weight hose. The techniques of transporting and emplacing the submersible pump and the lightweight generator will require further test to explore all possibilities of use in connection with the 8-inch hoseline.

c. Fire Tests. The breadboard-model convection water-fog generator could have been more effectively used if it had been easily portable. The number of nozzles on the model was limited to a practical quantity resulting in a coarser water-fog than was desired. The optimum particle size for minimum fallout rate was calculated to be 75 microns, whereas the particle size developed by the model of Bete nozzle used was in the 300 to 500 micron range. The weak fire in Fire Test No. 1 did not engender adequate indrafts required to draw the water-fog in. Most of the water-fog dropped out within 20 feet of the generator, and the estimated 300 gpm which probably reached the fire was not sufficiently dense. In a situation where the indrafts are weak, a forced-air current to help carry the water-fog into the fire would be desirable. A fire ten or more times as large would be required to generate an indraft significantly great to produce the desired results and to minimize the effects of ambient wind conditions.

As may be noted in the test results, many of the individual nozzles of the breadboard fog generator were plugged with debris, mostly of vegetable origin during the course of the tests. Although the nozzles were of the non-clogging type where size of foreign matter was limited, clogging with items such as sticks and pebbles proved to be progressive in a given nozzle, i.e., one piece of extraneous matter would not in itself render a nozzle inoperative, but an accumulation of such matter would nullify the nozzle function.

Test experience with clogging nozzles indicates the necessity of considering the fire-fighting equipment susceptible to extraneous matter in the water supply and the possibility that additional strainers of finer mesh will be required in the water supply system. A screen is currently integrated into the submersible pump unit.

d. Protective Clothing. The expendable aluminized fire fighter's ensembles proved to be usable by field troops with no further instructions than to don the suits. The suits significantly increased the men's ability to approach a fire. The suits had a low wet strength and tore easily when exposed to the intermittent rain. The front edge of the helmet liner abraded through the paper at contact points. Further tests should be conducted in work situations to determine the wearer's ability to perform the necessary duties of the task while wearing the ensemble, and a reinforced paper with high wet strength should be used in construction of the suit. The relative merit of providing a shield for the feet or wetting the footgear should also be investigated since one of the most frequent causes for retiring from the fire was lack of protection for the feet.

None of the other clothing outfits were tested to the limit of their protection because the subjects retired from the fire vicinity due to excessive heat on the unprotected portions of their bodies, namely, hands and feet, and the tests were discontinued because of the lack of this protection. The fiberglas Swedish fire entry suit was not tested because of a tendency for the raw edges of fabric to produce a dermatitis.

e. Meteorological Support. Support furnished by the Signal Corps Meteorological Department, U. S. Army Electronic Proving Ground, was excellent, providing sufficient data to present a view of the state of the atmosphere around the fire (Appendix C). The complete microstructure of the atmosphere, however, is not shown in the data presented in the Signal Corps report since a very dense three-dimensional network of sensing elements would have been necessary to obtain such detail. Some of the sensing elements would probably have been destroyed or damaged by flames and heat, and fabrication of expendable items would have required a lead time of about 6 months.

The Signal Corps postulates that the air currents, described in paragraph 7f of this report, which prevented the formation of a convection cell over Fire No. 4 were probably due to the increased volume of air resulting from the expansion caused by the fire. Once the gravity-type wind had subsided, a convective-type cell was established over the bed of coals. The influence of the convection column overcame the gravity-type wind and deflected it

counter-clockwise (to the south) around the bed of coals. Together with a similar movement of the indraft from the opposite side, a counter-clockwise rotation was imparted to the thermal column.

IV. CONCLUSIONS

10. Conclusions. From observations made during the tests, it is concluded that:

a. The concept of assigning troops to fire fighting as a secondary mission (i.e., one other than that for which they have been trained) is valid provided that the operation requirements are no more complex than those required to operate automotive equipment.

b. A quick-coupling tubing system of the type used in the tests meets the requirements for a rapidly constructed emergency water-supply line. Its intrinsic simplicity permits the use of untrained troops in emergency fire-fighting operations. A more positive coupling than the Ames Co. model is needed for the terminal and nonrigid elements of an emergency water-supply line. The submersible pump is suitable for use as a draft or booster pump in emergency water-supply lines. It may require provisions for screening out extraneous matter where solid matter water source contamination exists.

c. Ground-air coordination for helicopter placing of hose and pump equipment as an emergency fire-fighting task force operation is feasible. Effectiveness of such an operation is ultimately dependent upon improvement of the technical performance of equipment and additional capabilities as follows:

(1) Providing operational control of the hose flaking out.

(2) Providing suitable equipment for air-to-ground-to-air movement of components and personnel where ground obstacles prevent helicopter landings.

d. The concept of convection water-fog generation for controlling large unconfined fires requires further study and testing, with consideration being given to conveying the water fog into the fire by forced air instead of relying solely on the generated drafts.

e. The expendable aluminized paper fire-fighter's ensemble can be used without prior instruction by field troops for protection against the thermal radiation of large fires. Further troop tests in work situations are indicated. Future ensembles should incorporate a stronger base material with high wet strength.

APPENDICES

APPENDIX A

AUTHORITY

SUBPROJECT OF PROJECT 8-76-04-200

R&D PROJECT CARD	TYPE OF REPORT: PROGRESS	REPORT CONTROL SYMBOL: CSCRD-1
PROJECT TITLE: ...OMIC FIRE FIGHTING TECHNIQUES AND EQUIPMENT (U)	SECURITY OF PROJECT: U; CETC NO. 2089/238	PROJECT NO. 8-76-04-21... ; REPORT DATE 31 Dec. 57
BASIC FIELD OR SUBJECT: ...ire Fighting	R&D FIELD OR SUBJECT SUB GROUP: Fighting, Fire	80-9
COGNIZANT AGENCY: ... of E	CONTRACTOR AND/OR LABORATORY: Eng Res & Dev Lab; Borg-Warner Corp.; B. F. Goodrich; Consolidated Diesel Elec.; Reed Research Corp.	CONTRACT/W. O. NO.: DA-44-009 eng-2640; DA-44-009 eng-2878; DA-44-009 eng-3002; DA-44-009 eng-3039
DIRECTING AGENCY: ...r. Res & Dev Div, TO, OCE		
REQUESTING AGENCY: OCE		
PARTICIPATING AND/OR COORDINATING AGENCIES: ...AF (C); ...hem Corps (C); CONARC (C); ...CN, Bu Y&D and Ships (C); ...TAF (C)	RELATED PROJECTS: 8-76-04-100	EST. COMPLETION DATES: RES. / DEV. / TEST / OP. EVAL.
	DATE APPROVED: 7 Nov 52 by CRUSA	FY / FUNDS ESTIMATED

...perredes project card dated 31 December 1956.

REQUIREMENT AND/OR JUSTIFICATION: There is a requirement in large military bases, in or ...tside the continental U. S. , for techniques, plans and equipment to control ...onflagrations caused by atomic warfare, to insure that injury of personnel, ...amage to materiel, disruption of communications, and loss of security of the ...ilitary mission, may be controlled and minimized. The plans, techniques and ...tems proposed for development under this project are such that the lack thereof ...uld result in the destruction of supply depots, headquarters, railroad yards, ...rt facilities, and similar facilities, thereby seriously handicapping logistic ...pport of military operations.

...RIEF OF PROJECT AND OBJECTIVE

a. Brief:

(1) Objective:

(a) To define the fire fighting problems resulting from Atomic Warfare including the effect of radioactivity on fire fighting operations.

(b) Establish a model fire fighting plan outlining techniques and equipment requirements.

(c) To establish, as required, the detailed military characteristics for new equipment determined to be essential in providing for fire fighting operations.

Fred S. Richter Iron Works DA-44-009 eng-3106

Best Available Copy

R&D PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
ATOMIC FIRE FIGHTING TECHNIQUES AND EQUIPMENT (U)	U	8-70-04-016
	4. 6 of 8	5. REPORT DATE 31 Dec. 57

(d) To develop such new items of equipment as may be required.

(2) Military Characteristics (General);

(a) Plans and equipment shall be such as to assure immediate fire fighting operations subject to arrival of the equipment in the conflagration zone.

(b) The equipment and techniques shall be suitable for use at military, civil and industrial installations.

(c) Standard engineer construction and demolition equipment shall be designated, as applicable, for area fire control.

(d) The equipment selected or developed shall be mobile and self-contained with respect to power supply.

(e) The model fire fighting plan shall be in sufficient detail to serve as the basis in establishing specific fire protection and fire fighting plans applicable to local conditions.

(f) Equipment shall be capable of satisfactory performance in any ambient temperature from +125 F with full impact of solar radiation of 360 BTU/Sq Ft/Hr for at least 4 hours to -25 F for at least 3 hours without benefit of solar radiation and shall not be damaged by storage at any ambient temperature of +160 F for periods of 4 hours per day -80 F for periods of at least 3 days duration.

(g) Air Transportability is required in Phase III of Airborne Operations.

(h) The equipment shall be radio suppressed in accordance with the pertinent standards of the Signal Corps.

b. Approach:

(1) A study will be made of all available data on the conditions in large populated areas resulting from atomic bombing in order to establish the criteria for fire fighting requirements.

(2) A study will be made of typical and specific layouts of water supply systems of larger European Cities which are potentially critical communication points by virtue of their position as ports or rail and communication centers and depots.

(3) Based on the studies outlined in (1) and (2) above a model fire fighting plan will be developed using latest technology in the field of urban fire fighting.

(4) Techniques for Atomic fire fighting will be studied and evaluated. Where practicable, tests will be conducted.

(5) Detailed military characteristics for new items of equipment, as required, will be established with recommendations for development as sub-projects under this project.

(6) Selection will be made of those items of military equipment now standard and essential to the execution of the atomic fire fighting plan.

DD PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
ATOMIC FIRE FIGHTING TECHNIQUES AND EQUIPMENT (U)	U	8-76-04-[illegible]
	4. C of 5	5. [illegible]

Block 21 continued

c. Subtasks:
The related project (No. 8-76-04-007, Truck, Fire, Military) will result in a superior type fire truck the characteristics of which are such as to indicate suitability for Atomic Warfare firefighting.

d. Other Information:

(1) References:

(a) "Civil Defense for National Security," OCDP, 1948.

(b) "Medical Aspects for Atomic Weapons," NSRB, 1950.

(c) In the above reports it was stated that much damage could have been avoided in Hiroshima and Nagasaki if adequate fire protection had been available. As a result of large-scale enemy action on a point of high population density, numerous and scattered fires soon result in a larger conflagration known as a fire storm. A period up to 10 minutes may lapse between the time the various fires initiate to the time the fire storm develops. During this period, the plan of attack for fire control must be made and initial action taken in order to ultimately control the resulting fires with a minimum loss of material and life.

(2) Discussion:
Agencies interested in this project, in addition to the Corps of Engineers, with which liaison will be maintained and which will be furnished copies of reports on the project are the Atomic Energy Commission, Department of the Navy, Department of the Air Force, Army Technical Services, CONARC, Federal Civil Defense Administration, and the Department of Agriculture, Forest Service.

APPENDIX B

TEST PERSONNEL

1. TECHNICAL GROUP

Mr. John F. Christian, ERDL, Ft Belvoir, Va, Technical Director
Mr. John D. Grabski, ERDL, Ft Belvoir, Va, Equip Supervisor
Maj Albert Krauze, The Engineer School, Ft Belvoir, Va
Col William Mantz, Office of Secretary of Defense, Wash., D. C.
Sp2 Charles J. Waller, Preparations Supervisor

2. ENGINEER SUPPORT UNITS

Company C, 34th Engineer Battalion (C), Ft Lewis, Wash., Capt Charles M. Boswell, Commanding Officer
Company B, 35th Engineer Battalion (C), Ft Lewis, Wash., Capt Donald E. Burke, Commanding Officer
2d Lt Thomas F. Veale, Co C, 35th Engr Bn (C), Liaison Officer, Test Control Hq
MSgt Bobby O Foster, Co A, 35th Engr Bn (C), Administrative NCO, Test Control Hq

3. METEOROLOGICAL GROUP

1st Lt Paul F. Wilkinson, Meteorological Company Ft Huachuca, Ariz., plus 8 EM
Mr. Roswell Walker, DAC, Meteorological Dept, Ft Huachuca, Ariz.

4. COMMUNICATIONS GROUP

Sp2 Richard W. Temple, Hq 116th Engr Gp (C), Ft Lewis, Wash.
Pfc Ronald C. Crawford, Hq 116th Engr Gp (C), Ft Lewis, Wash.

5. PHOTOGRAPHIC SUPPORT

Sgt Edward F. Doyle, Signal Photo Lab, Ft Ord, Calif., 6th Army Photo Lab, Presidio of San Francisco, Calif., plus 2 EM

6. AIR SUPPORT

33rd Transportation Helicopter Co, Ft Ord, Calif. (2 H-21C Helicopters)
Maj Keith J. Bauer, Commanding Officer
Capt Neville A. Pearson, TC
1st Lt J. D. Horne, Jr., TC
CWO-2 John J. Cooney plus crew of 4 EM

7. THERMAL RADIATION TEAM

California Forest & Range Experiment Station, USFS, Berkeley, Calif.
Mr. Arthur Pirsko
Mr. W. T. Pong
Mr. Samuel Richards
Mr. W. L. Fons

8. CIVIL DEFENSE SUPPORT

Chief "Hap" Miller, Weaverville Fire Department

APPENDIX C

METEOROLOGICAL SUMMARY FOR MASS-FIRE CONTROL TEST
SPONSORED BY U. S. ARMY ENGINEERS
RESEARCH AND DEVELOPMENT LABORATORIES
October 1957

December 1957

Meteorology Department
U. S. ARMY ELECTRONIC PROVING GROUND
Fort Huachuca, Arizona

TABLE OF CONTENTS

METEOROLOGICAL SUMMARY FOR MASS-FIRE CONTROL TEST SPONSORED BY U. S. ARMY ENGINEERS RESEARCH AND DEVELOPMENT LABORATORIES
October 1957

1. General

Meteorological observations were taken to measure the effect of a burning crib upon ambient conditions. The crib consisted of logs which were stacked about 10 feet high over an area 25 by 160 feet. This test was conducted in a narrow valley within the Shasta-Redding National Forest at 40° 50.5' north latitude and 122° 49.6' west longitude. The valley is formed by the Stuart Fork of the Trinity River and is oriented along an east-west line. At the test site the floor of the valley is 2,160 feet above sea level and rises to 3,000 feet one mile south and 1½ miles north. The valley floor is comparatively free from trees for a width of one-half mile and it narrows gradually to the west.

2. Test Site

The Test Crib Nr 4 was designated for instrumentation as a control site. Meteorological instruments were oriented along a line perpendicular from the midpoint and extending in an east and west direction. A schematic drawing of the instrumentation is shown in Figure 1. The fire at Crib Nr 4 was started at 1640 on 11 October 1957.

3. Reliability of the Data

a. The enclosed meteorological data are considered to be of good quality; however, they have limitations. To assist in using these data most effectively, a brief outline of these limitations is listed below. Possible sources of error which impose limitations on the use of these data may be divided into three groups; namely, instrumental error, data reductions and processing error, and non-representativeness of data due to overall instrumentation.

b. Instrumental error entering into these data is considered to be small. Both the instruments and techniques used to collect these data were the best currently available.

c. Error entering through the reduction and processing of the data (reading autographic charts, computing upper winds from raw data, etc) is considered significant. The numerical values of accuracy listed below are approximate and will give the user an idea of the relative precision of the data:

(1) Hygrothermograph and thermograph data

(a) Time ± 10 minutes.

(b) Temperature within 2°F.

(c) Relative humidity within 5%.

(2) Beckman and Whitley wind data (surface wind)

(a) Speed within 1 mile per hour.

(b) Direction within 5 degrees.

(3) Double theodolite data (Upper winds).

(a) Balloon height within 2%.

(b) Wind speed within 1 mile per hour.

(c) Wind direction within 5 degrees.

d. The instrumentation of the project was good and data therefrom are sufficient to give an idea of the state of the atmosphere around the fire. However, the complete micro-structure of the atmosphere is not seen by examination of the enclosed data. A very dense three-dimensional network of sensing elements would be necessary to obtain the data necessary for such a detailed measurement of conditions.

4. Observational Data

a. Temperature and Humidity

(1) An effort was made to measure the ambient free-air temperature and relative humidity by instruments shielded from the influence of radiant heat. Bendix-Friez Model 594 hygrothermographs were installed at Stations W-1, W-3, E-1 and E-3. At Stations W-2 and E-2 thermographs ML-77 were installed. These instruments were installed in instrument shelters ML-41-B whose floors were four feet above the ground. The doors of the shelters on the west side of the crib opened to the south and the doors of the shelters on the east side opened to the north, thus permitting a common orientation of all sensing elements toward the fire. The relative humidity sensor was a hair element with periodic calibration checks made by a mercury-in-glass psychrometer ML-24. The temperature element was a Bourdon tube with calibration checks made by maximum thermometer ML-4 and minimum thermometer ML-5 permanently installed inside the shelter.

(2) Data from these instruments are presented in Figures 2 and 3 as enlargements of the basic autographic traces from 1600 to 1900 PST. Owing to the westerly winds the trace at Station W-1 showed only a minor increase in temperature at the maximum intensity of the fire whereas no corresponding changes were noted at Stations W-2 and W-3. The greatest influence on ambient temperature was recorded at Station E-1 where the temperature increase was over ten degrees higher than surrounding stations. Minor fluctuations of a few degrees were recorded at Station E-2 and no change in ambient temperature was noted at Station E-3. The relative humidity at Stations W-1, W-2, and E-3 behaved in a manner typical of normal conditions whereas the relative humidity at Station E-1 was influenced generally inversely to the temperature and a value was recorded roughly 45% lower than the other stations.

b. Surface Wind Speed and Direction

(1) The speed and direction of the wind near the ground were measured at all stations by the sensitive Wind Speed and Direction Recording System, Beckman and Whitley Model K100A whose sensors were positioned five feet above the ground and sufficiently removed from the instrument shelter to minimize local effects. Due to the positioning of these instruments, it is felt that the data contain no bias as a result of the eddies caused by the instrument shelter, but Station E-1 was apparently influenced by the proximity of the crib. The data were continuously recorded by Esterline Angus recorders having a paper feed of twelve inches per hour. Data were summarized from 1610 to 1830 PST by computing average speed and direction in five-minute increments and the deviation (range) from each five-minute period. Tabular forms of this data are presented in Tables 1 and 2. These averages are presented in graphical form in Figures 4 and 5. The averages are indicated by vectorial arrows positioned to show the direction in which the wind is moving and whose length denotes the speed. Each small square of the graph equals one mile per hour. Arrows shown in dashed lines indicate that data which were estimated. By the time the fire was started the test area was under the influence of a gravity type wind caused by cool air flowing down from the mountain slopes. This gravity wind reached its maximum around 1715 hours and diminished gradually thereafter. The influence of this wind affected the wind direction on both sides. In fact the flames and smoke were observed to move out sharply with the wind and this offset the possibility of forming a typical convection type cell with corresponding indrafts from the leeward side.

(2) The dominant feature from the wind data at this time was the nearly three-fold increase of wind speed on the leeward side without any corresponding change in direction compared with the windward side. The primary reason for this increase is believed to

be the increased volume of air resulting from the expansion caused by the fire. Following 1740 the flames were no longer the dominant feature of the fire and quickly reduced to embers. The resulting bed of live coals continued to give off significant amounts of heat beyond 1800 hours. Therefore by 1750 the gravity type wind had slowed down sufficiently to permit the induction of a convective type cell over the bed of coals and thereafter the wind recorded on the east side of the fire began to flow into the fire and oppose the natural circulation on the west side. Thus it was shown that for the period of record the wind on the west side veered clockwise about 45° as the windspeed decreased. This is consistent with what would normally be expected as the frictional component (resulting from the surface) decreased. At the same time the wind on the east side backed counter-clockwise about 90° showing the increasing effect of the fire with time.

c. Upper Air Wind Speed and Direction

(1) Measurements of the wind speed and direction above and adjacent to the fire were taken using the double theodolite technique. This procedure best establishes an excellent three-coordinate position of the balloon. Two double theodolite systems were employed using base lines of approximately 300 yards oriented north-south with each baseline about 150 yards to the east and west of the fire. Remote simultaneous releases were made from corresponding Stations 1, 2, and 3 on each side of the fire. The ascension rate of the balloons was approximately 150 yards per minute and readings were taken on the position of the balloons at 20-second intervals. Figures 6 thru 21 are plots of the wind speed and direction as a function of height from 1547 through 1737 hours. Additional plot shows the height of the balloon as a function of time. From the 20-second readings the mean wind speed and direction were computed for each horizontal stratum traversed by the balloon in that interval and therefore it has been plotted for the midpoint of the corresponding stratum.

(2) Figures 22 thru 30 depict the horizontal position of the balloon at 20-second intervals with respect to the crib. Although these Figures show that the balloon released from the west stations in nearly every case passed over the fire at a height of less than 50 yards there was less influence on its ascensional rate than the balloons released on the east side. This observation and the greater speeds shown in the lower levels from the balloons released on the east side infer the slope of the heated air with respect to the ground and suggest that for the most part the balloons released from the west side were in an environment unaffected by the fire.

d. General Weather

(1) The weather for northern California for a period of several weeks prior to the test was characterized by a series of low pressure areas moving in from the west with attending abundant rainfall. The normal weather pattern for the month of October is characterized by large percentage of sunshine and about five days having a rainfall of a hundredth of an inch or more. The departure from normal conditions experienced prior to the test has a probable occurrence of about once per 80 years and considerable publicity attended this unusual weather in press and radio releases. The frequent occurrence of rain and the nearly continuous cloud cover resulted in the maximum saturation of exposed timber and the ground with virtually no opportunity for intervening drying periods.

(2) Crib Nr 3 was ignited on 9 October 1957 at 1527 PST. The sky was overcast with low clouds and there were patches of fog on the floor of the valley. There was very light rain falling at the time and it continued intermittently for the rest of the afternoon. The wind above the valley was moderate from the south, but at the test site the wind was variable in direction and light in speed as a result of large scale eddy motions set up below the crest of the ridges.

(3) Crib Nr 1 was burned on 11 October in mid-morning. Crib Nr 2 was burned in the early afternoon and Crib Nr 4 was ignited at 1640 of the same day. The 11th of October was characterized by a break in the previous foul weather regime and the overcast began dissipating around 0900 and rapidly cleared with the exception of a few distant cumulus type clouds. The wind speed at the test area was very light until about 1600. The fire from Crib Nr 2 apparently set up a nearly ideal convective type circulation and caused the formation of a cumulus cloud about 4,000 feet over the fire. The cloud persisted for over an hour. By 1630 the cooling of the air near the surface caused by the low angle of the sun caused a gravity type wind in the test area. Figures 6 thru 21 show that the gravity type wind remained comparatively shallow (maximum depth about 400 yards). The clear sky and light winds after sunset caused rapid cooling of the ground, and groundfog began before midnight.

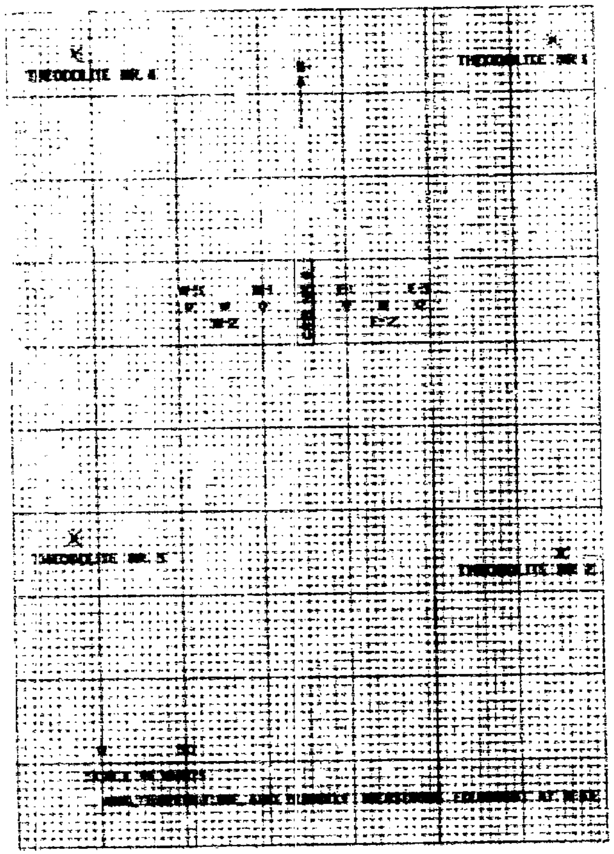


Fig. 1. Layout of instruments.

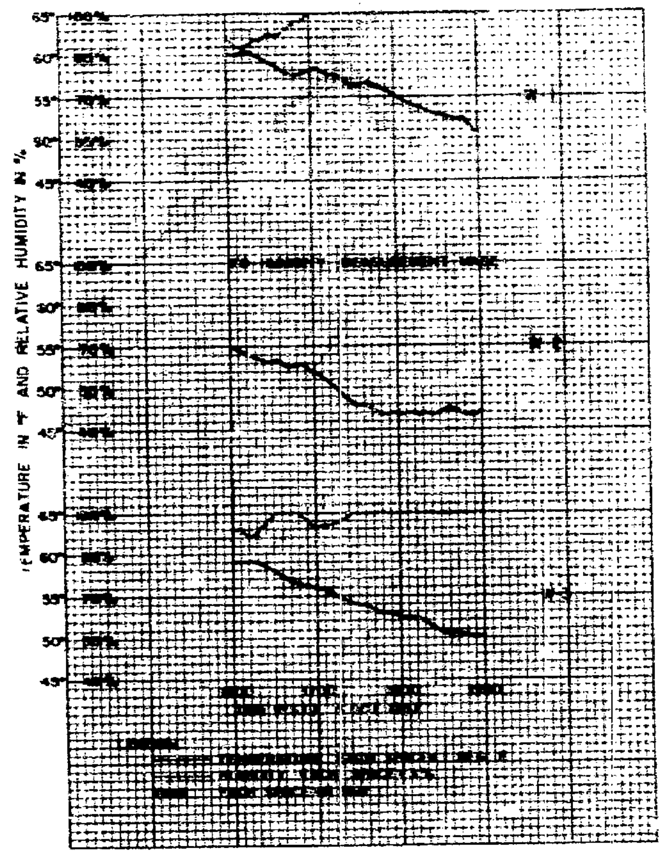


Fig. 2. Thermograph and Hygrothermograph Data.

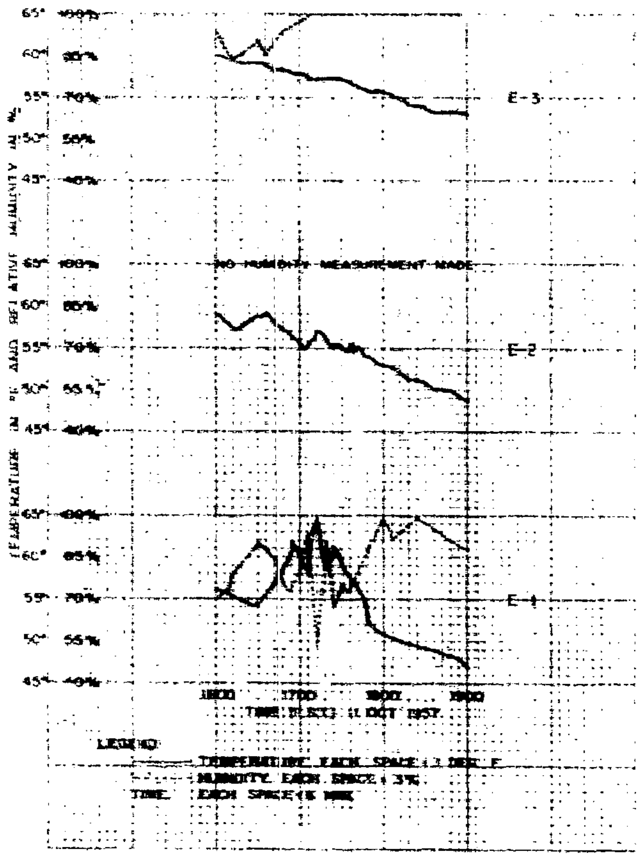


Fig. 3. Thermograph and hygrothermograph data.

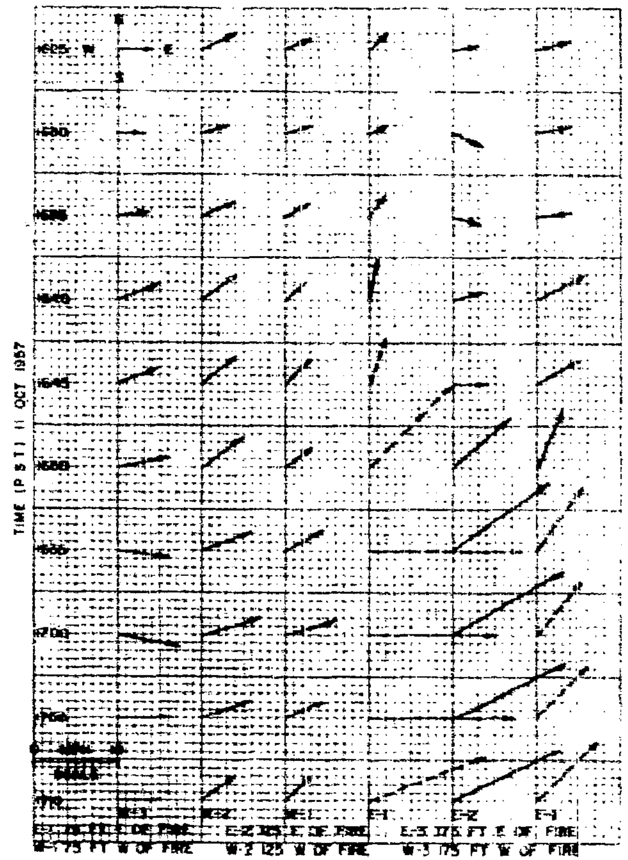


Fig. 4. Surface wind data.

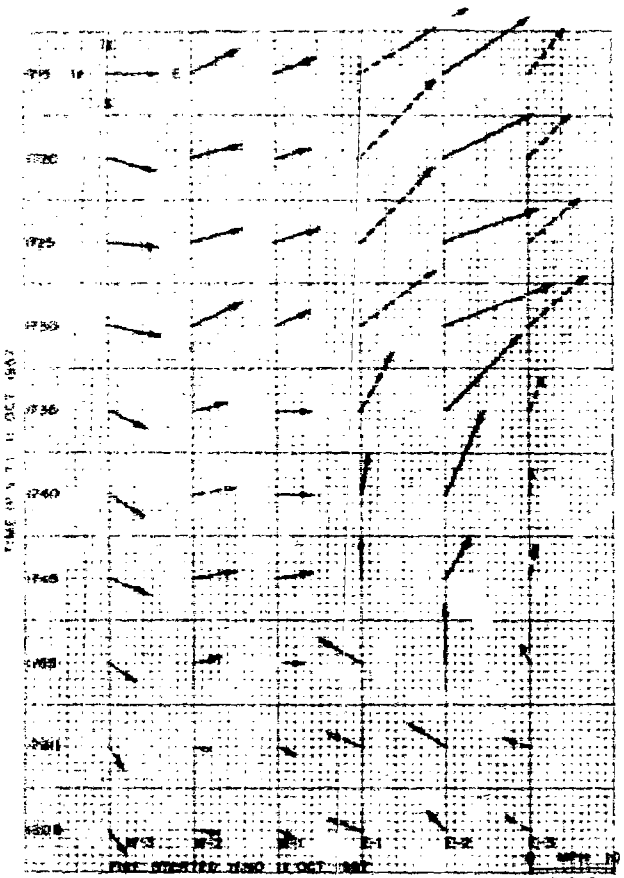


Fig. 5. Surface wind data.

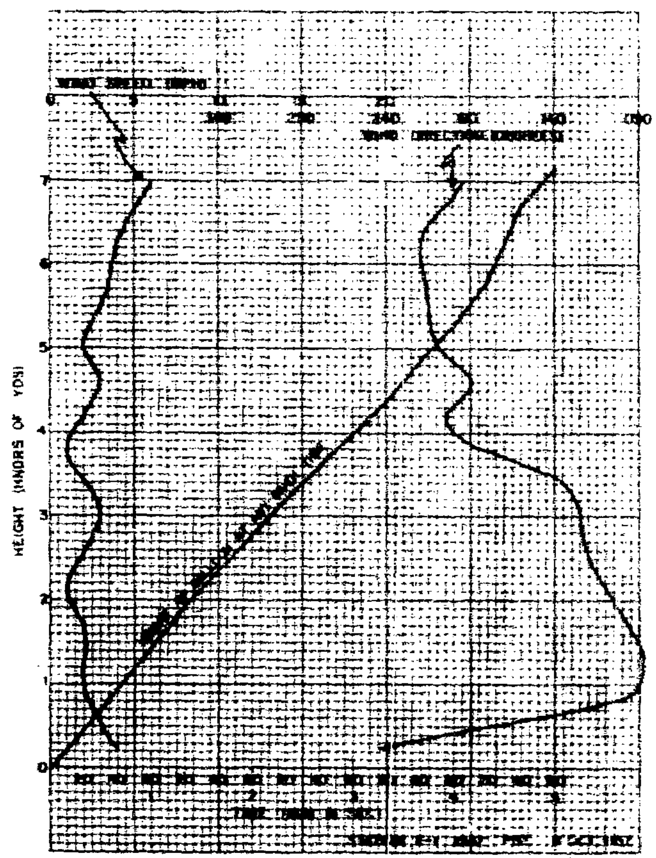


Fig. 6. Upper winds.

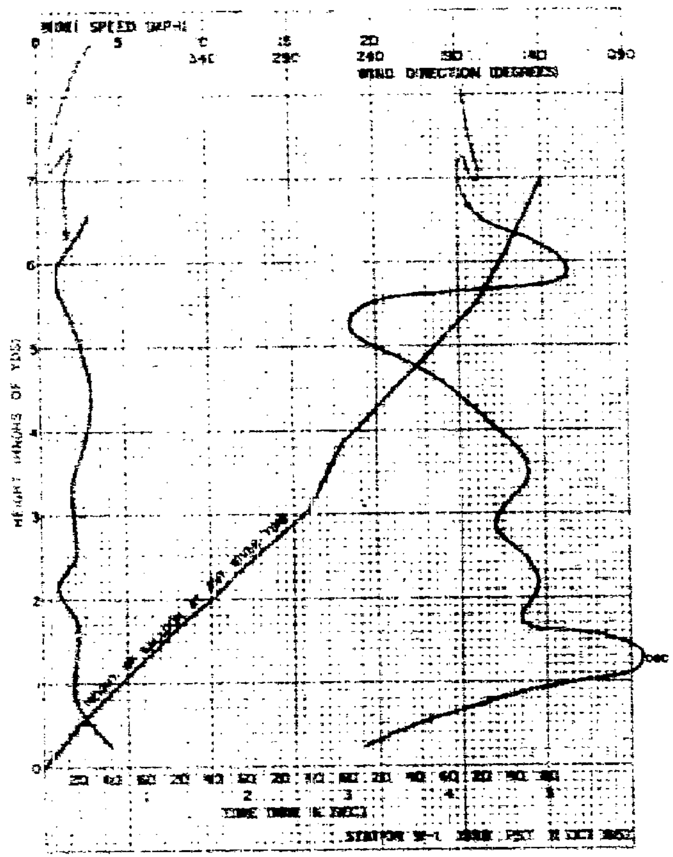


Fig. 7. Upper winds.

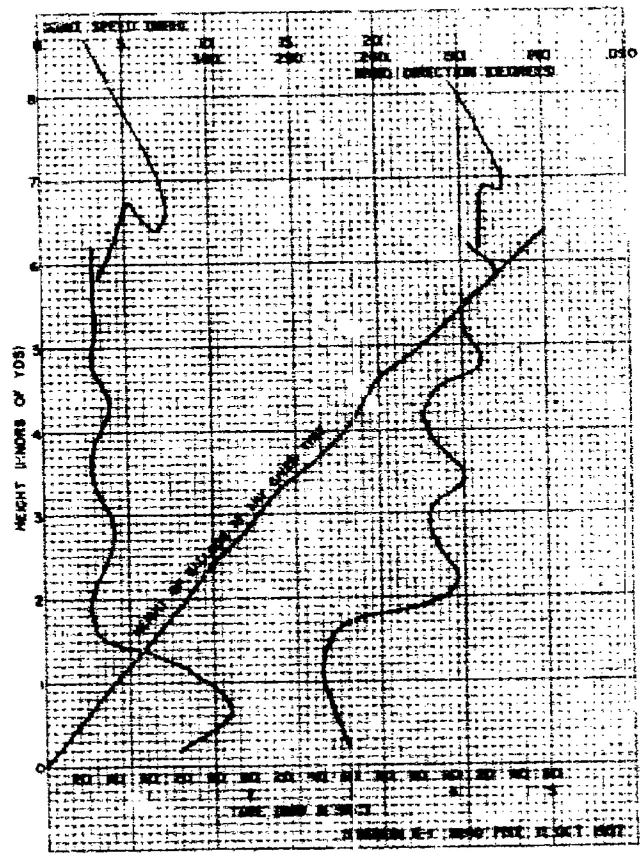


Fig. 8. Upper wind.

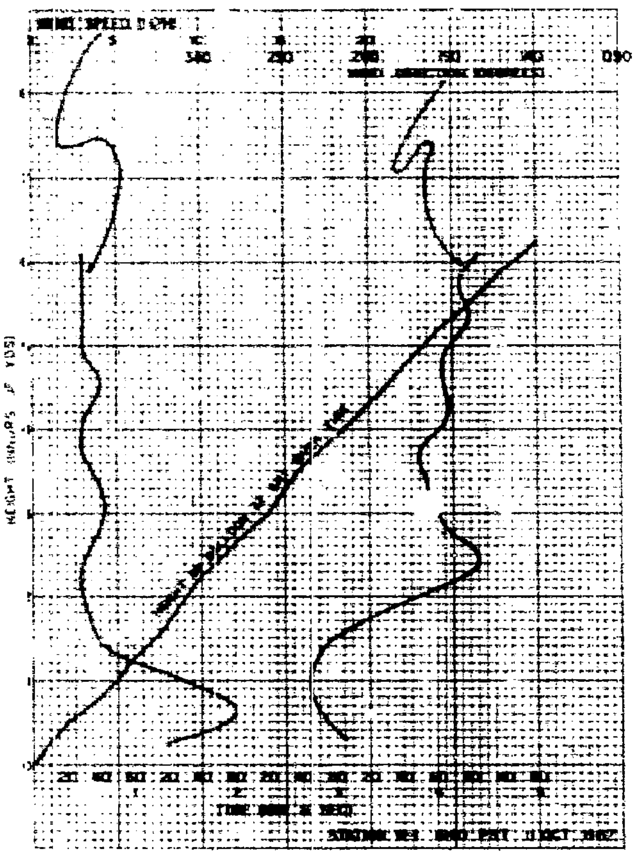


Fig. 9. Upper winds.

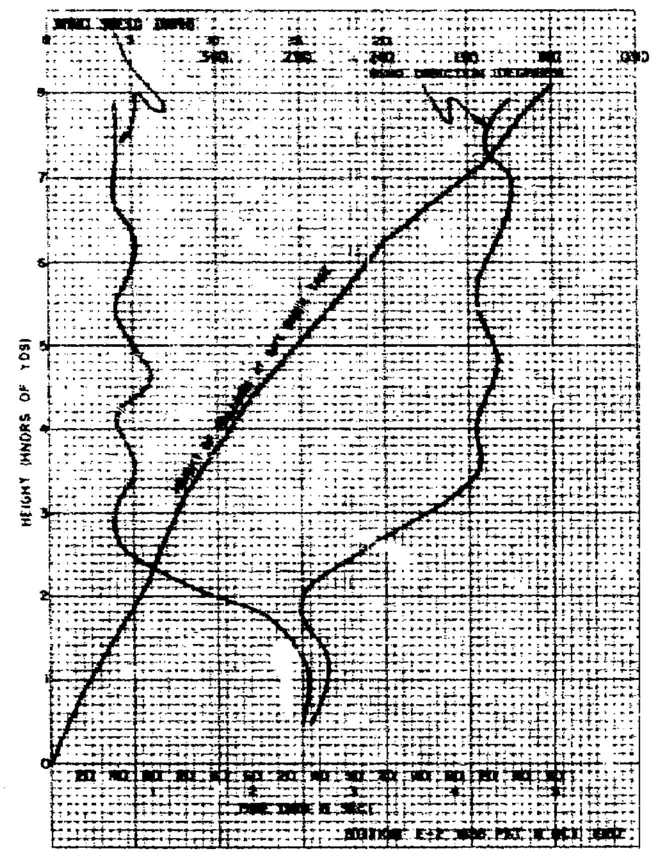


Fig. 10. Upper winds.

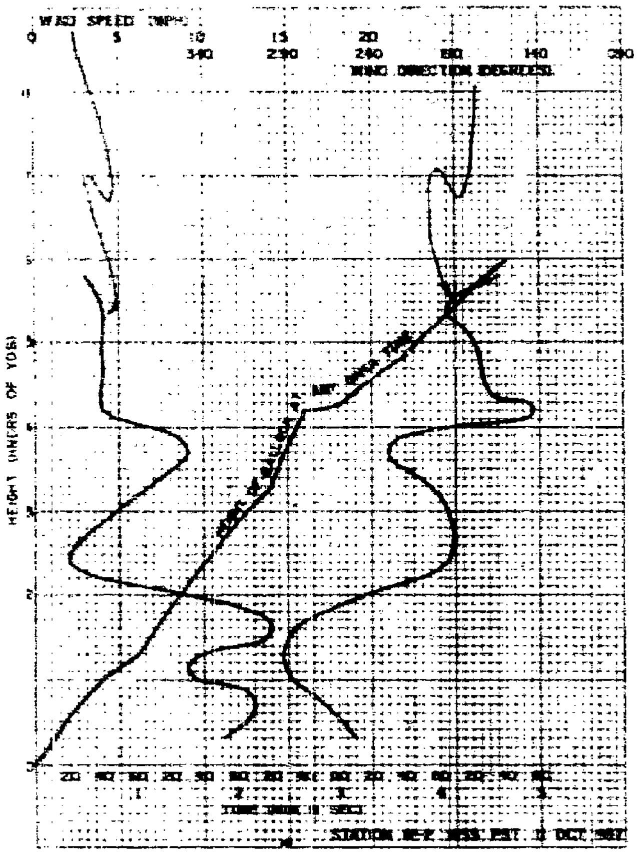


Fig. 11. Upper winds.

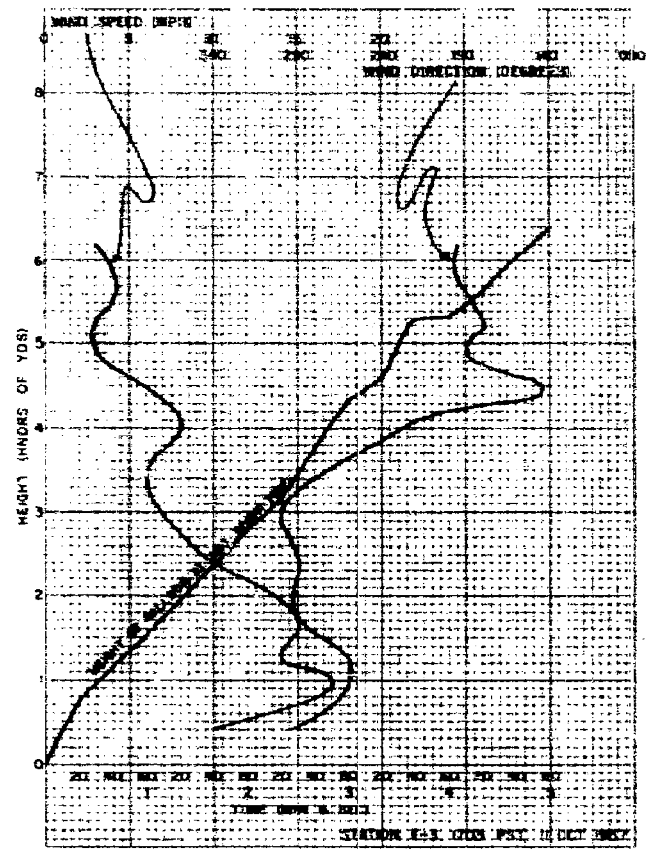


Fig. 12. Upper winds.

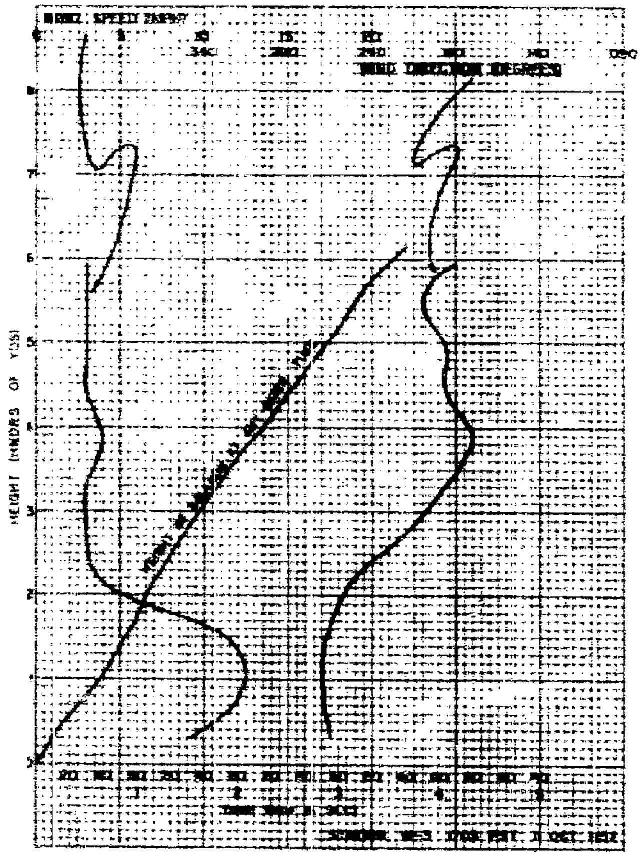


Fig. 13. Upper winds.

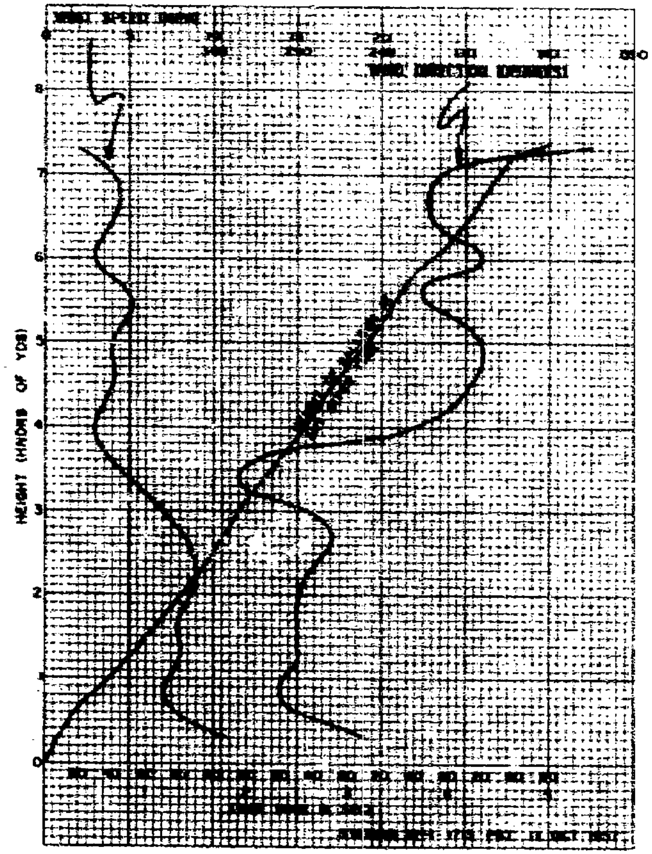


Fig. 14. Upper winds.

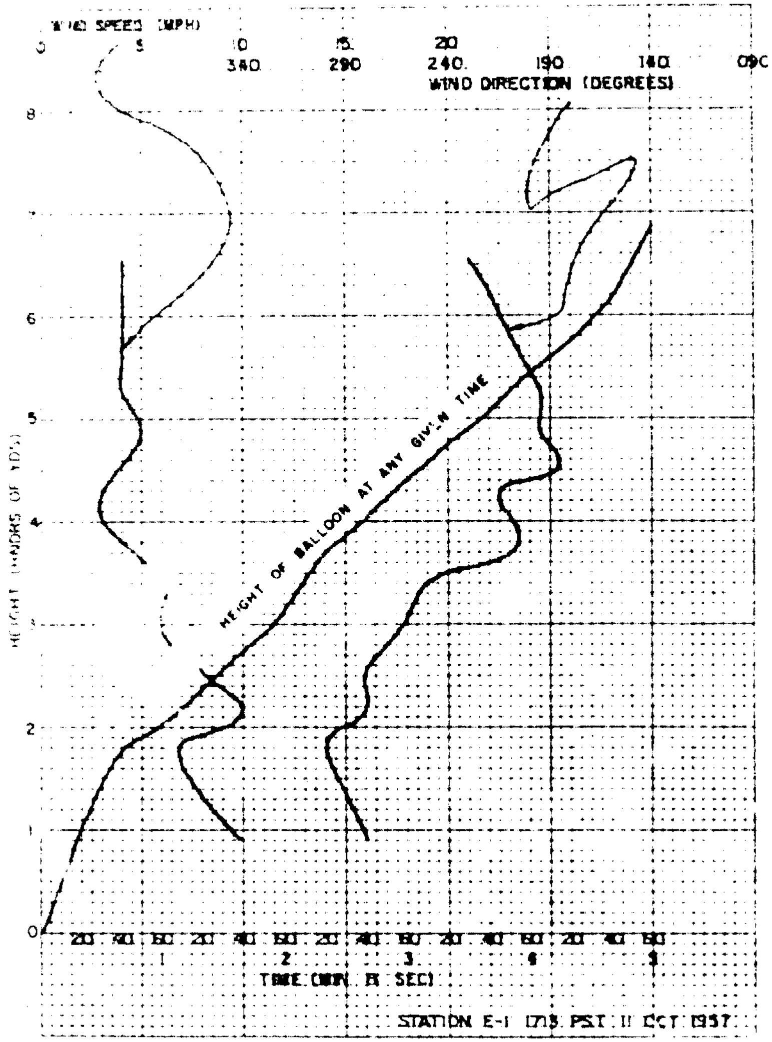


Fig. 15. Upper winds.

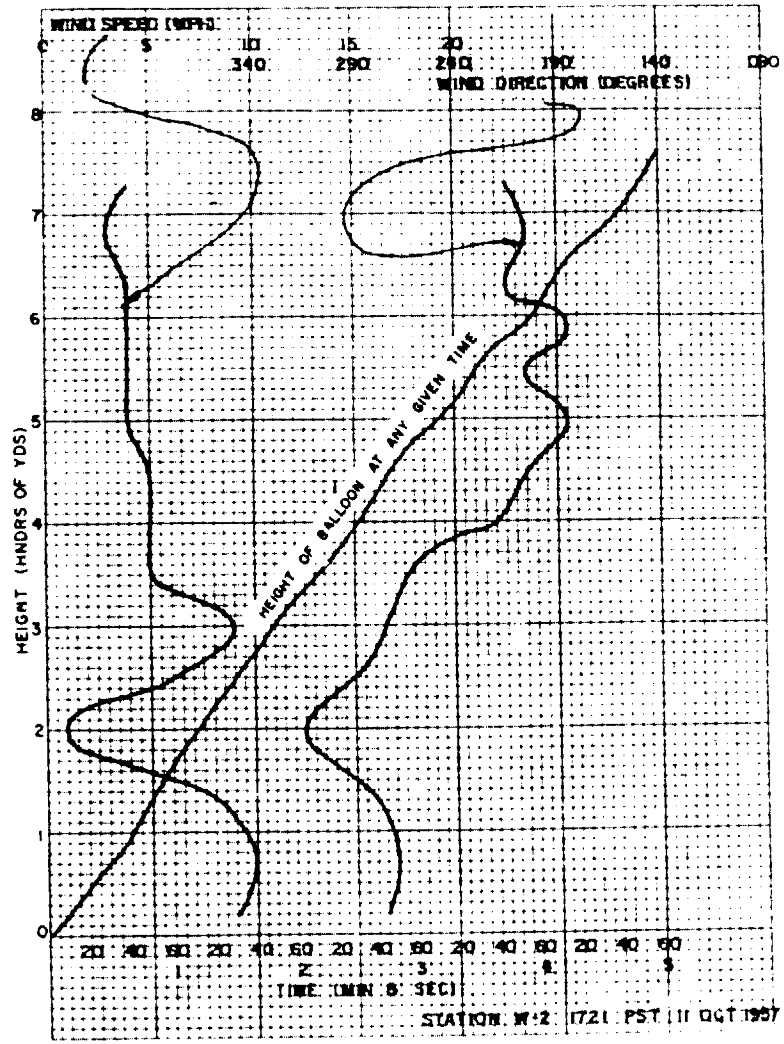


Fig. 16. Upper winds.

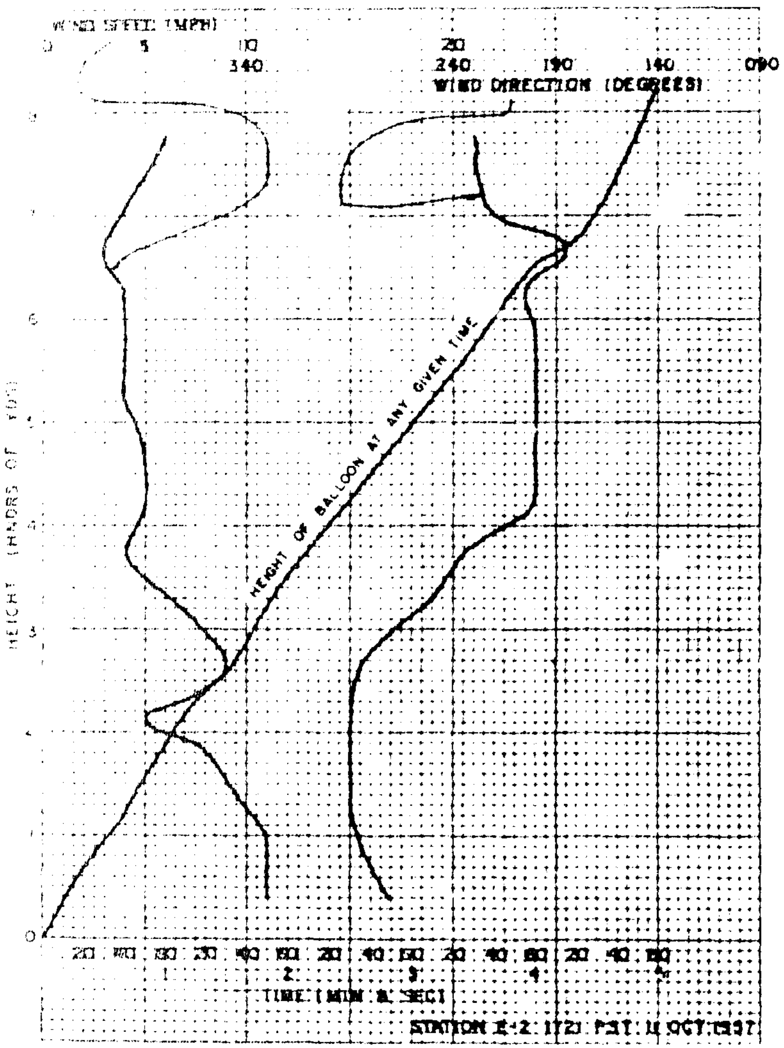


Fig. 17. Upper winds.

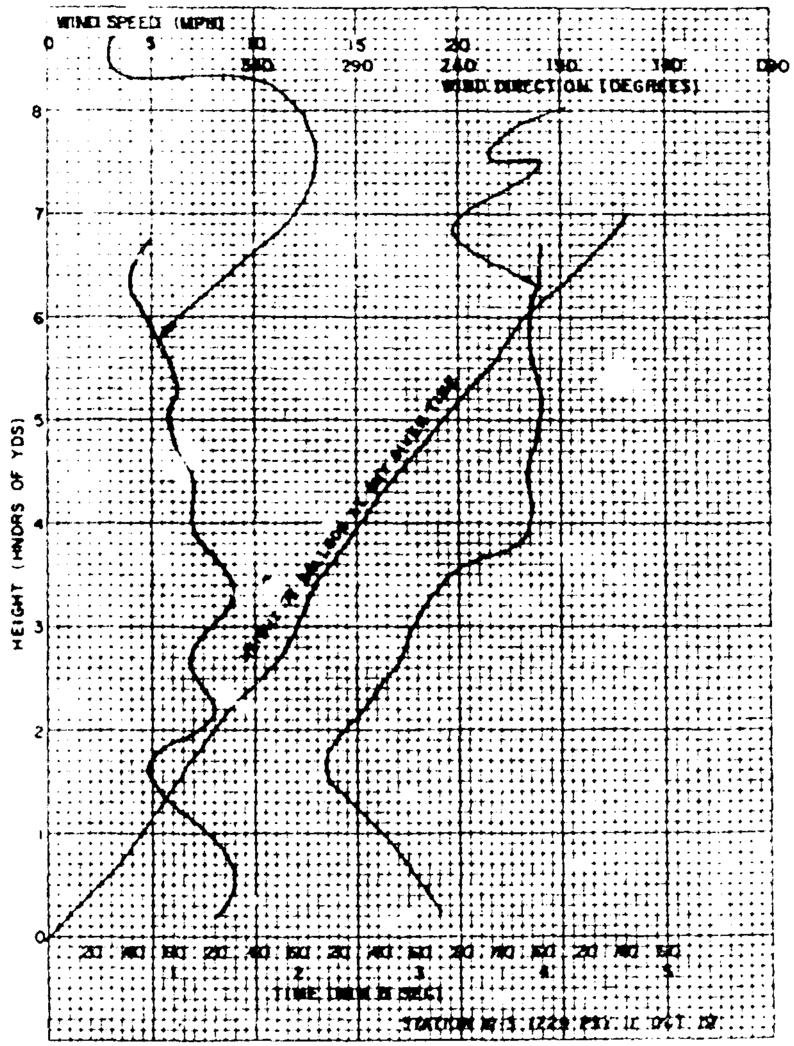


Fig. 18. Upper winds.

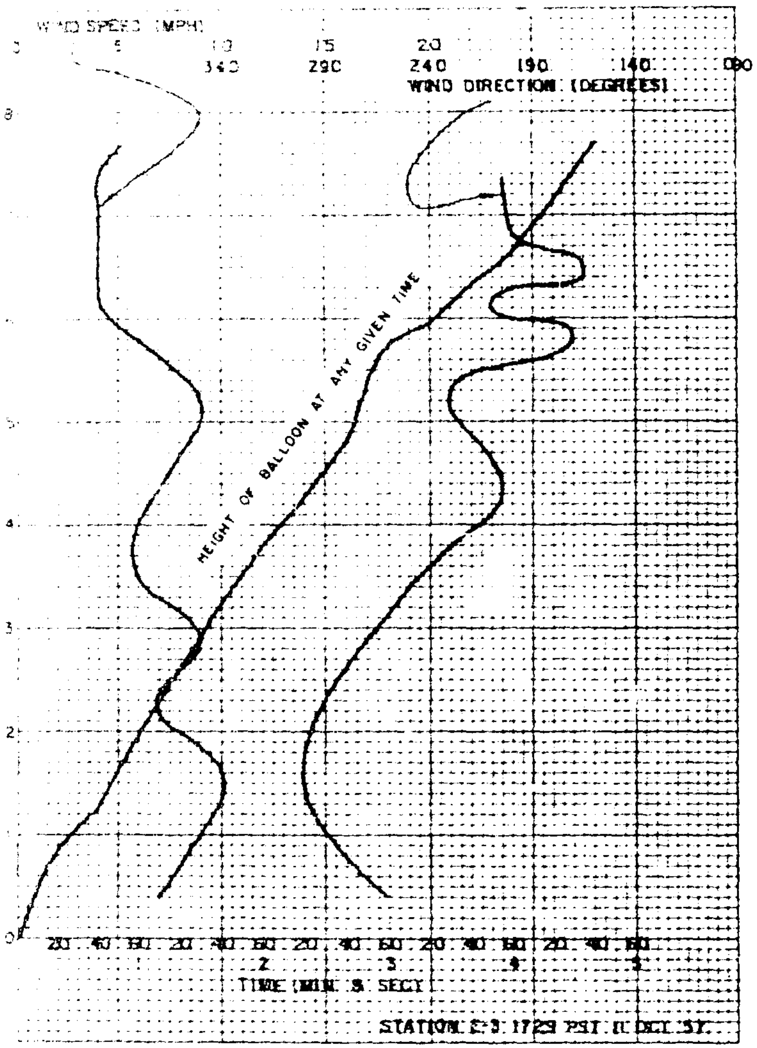


Fig. 19. Upper winds.

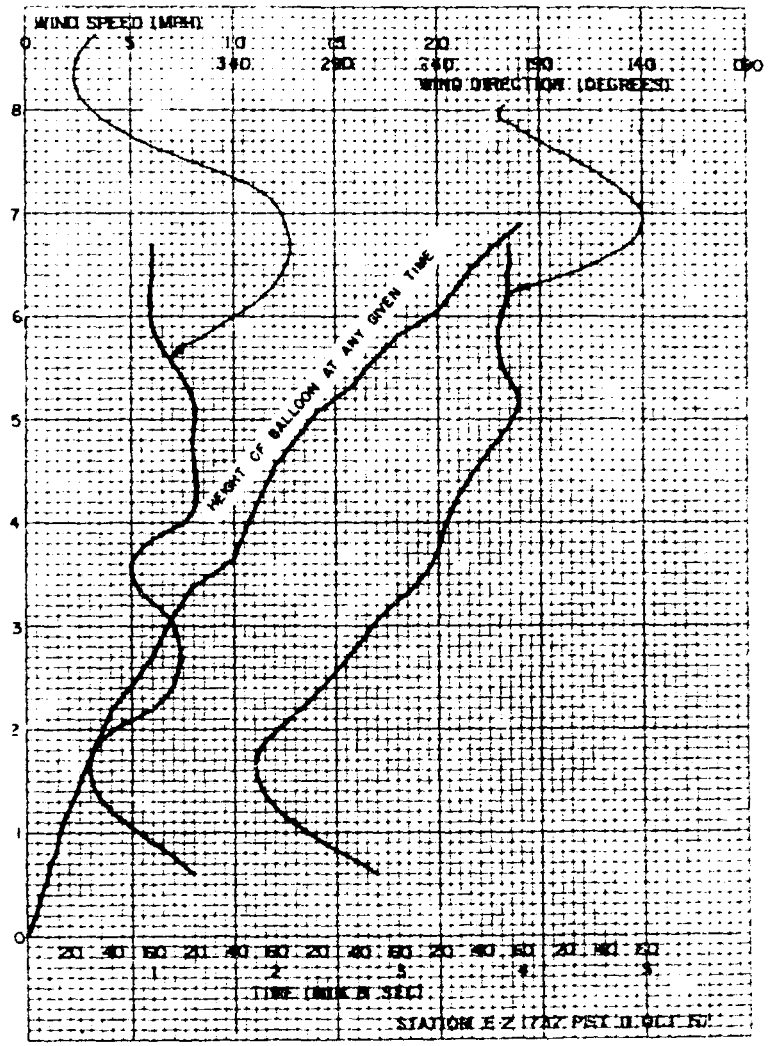


Fig. 20. Upper winds.

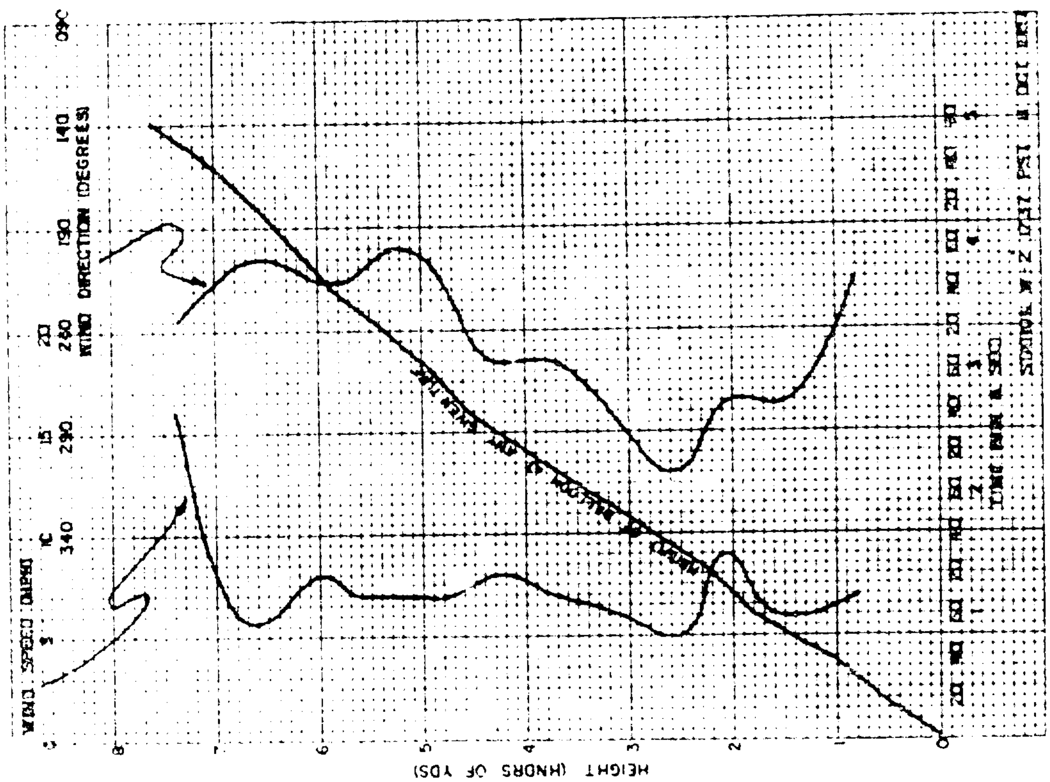


Fig. 21. Upper winds.

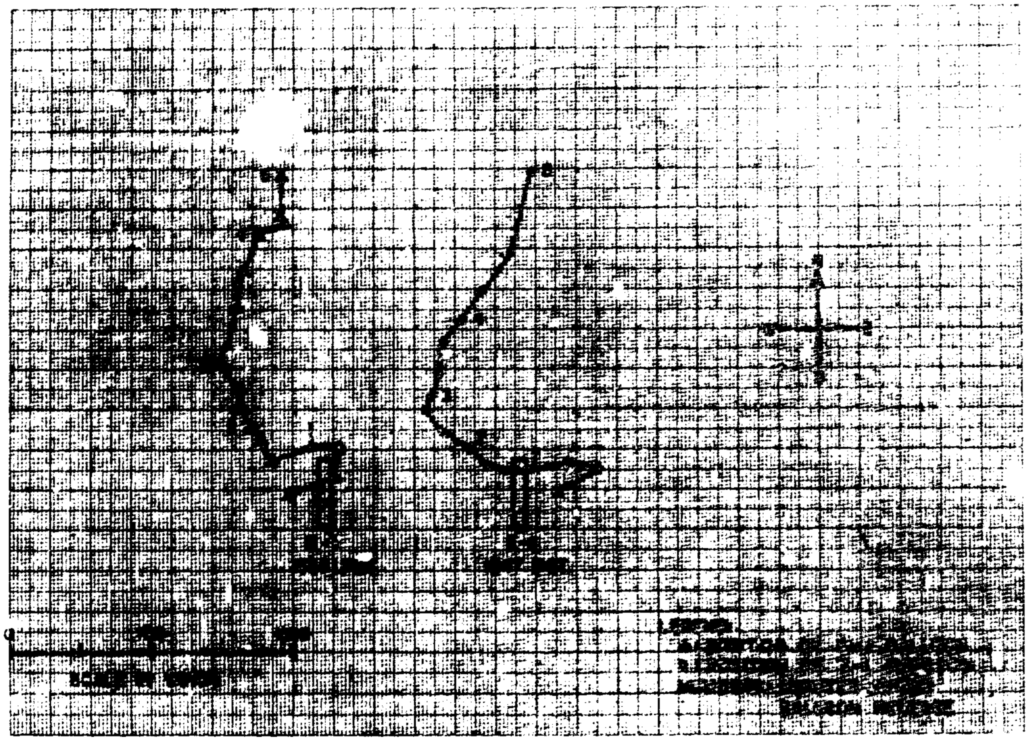


Fig. 22. Balloon trajectories.

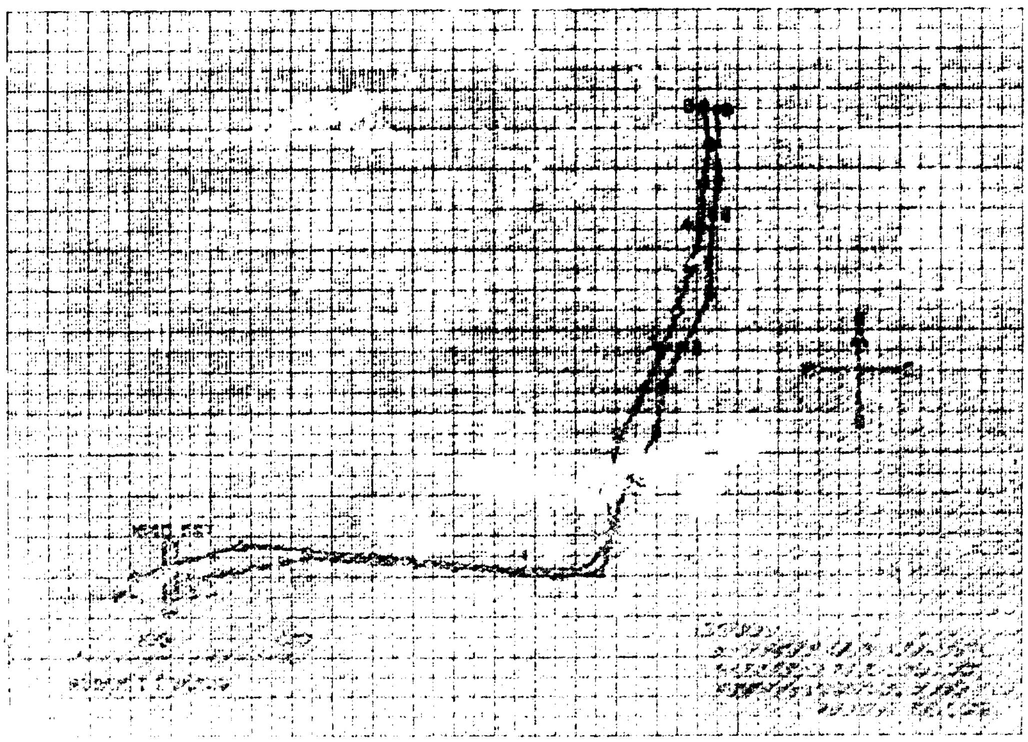


Fig. 23. Balloon trajectories.

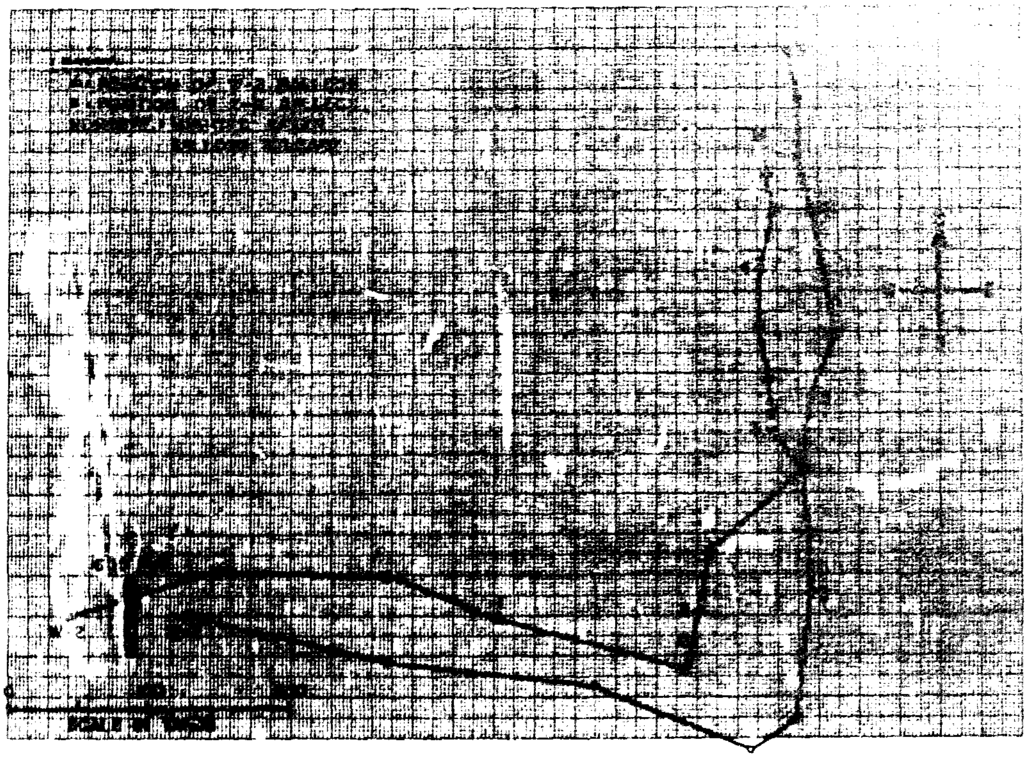


Fig. 24. Balloon trajectories.

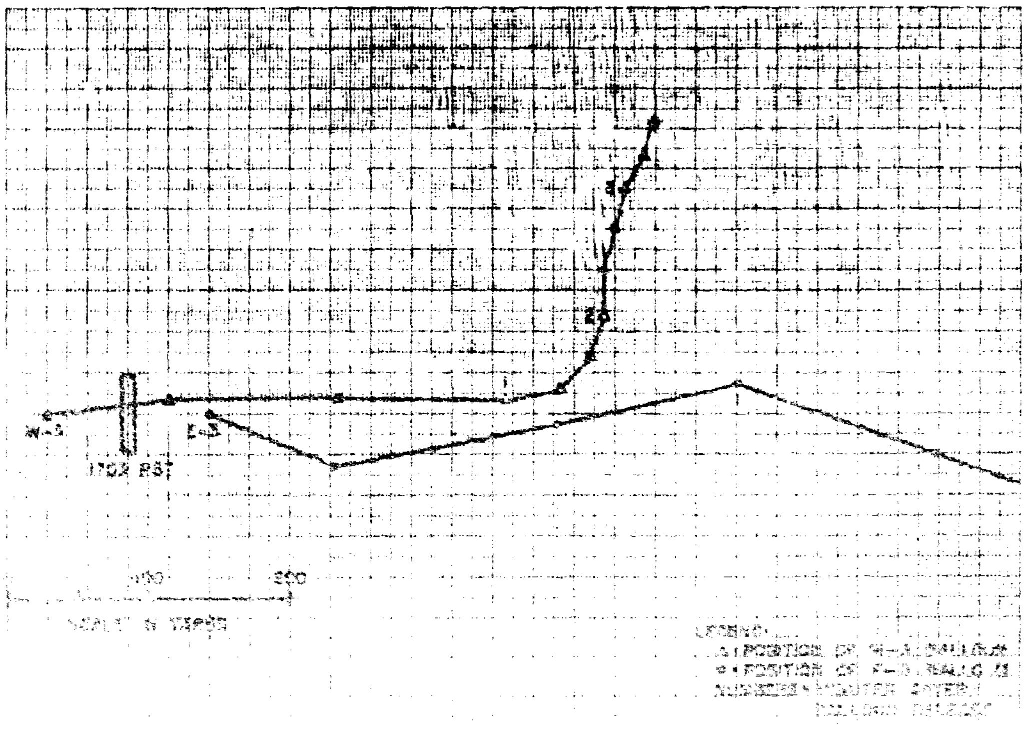


Fig. 25. Balloon trajectories (continued on Fig. 25A).

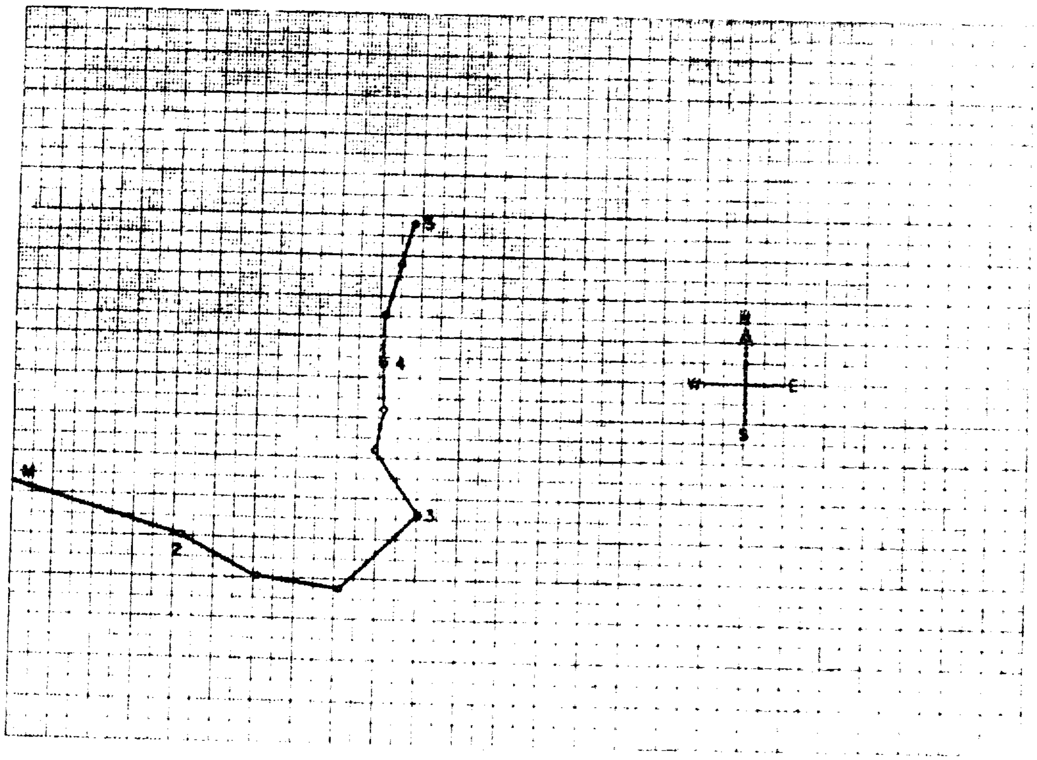
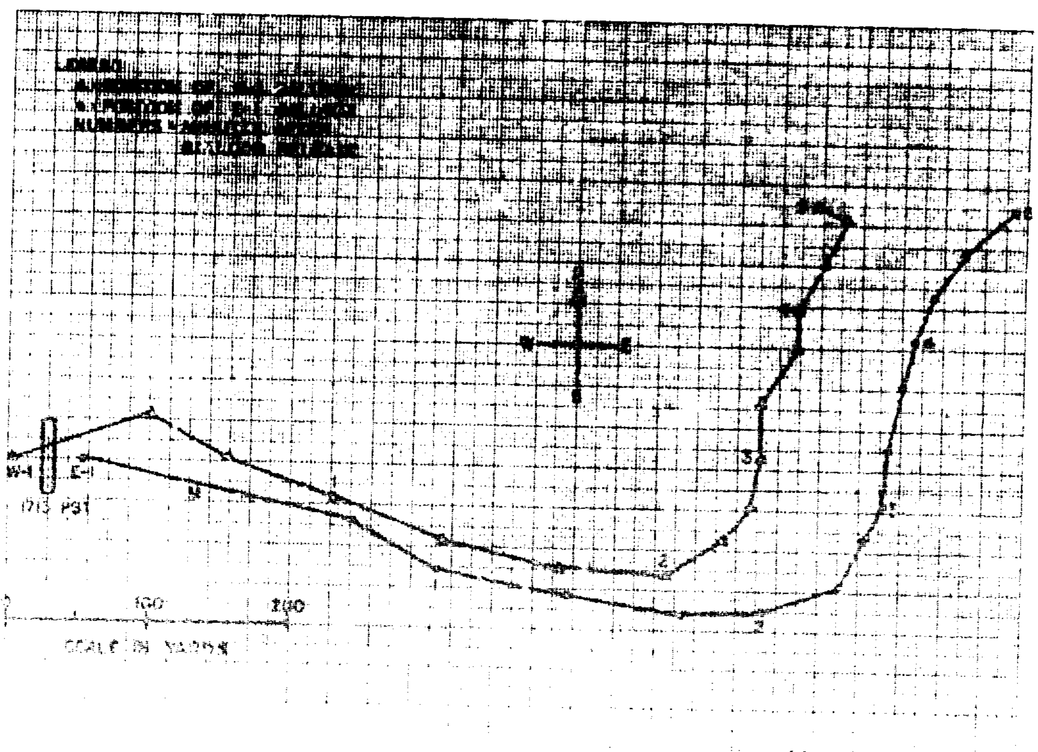


Fig. 25A. Balloon trajectories.



[illegible] Balloon trajectories.

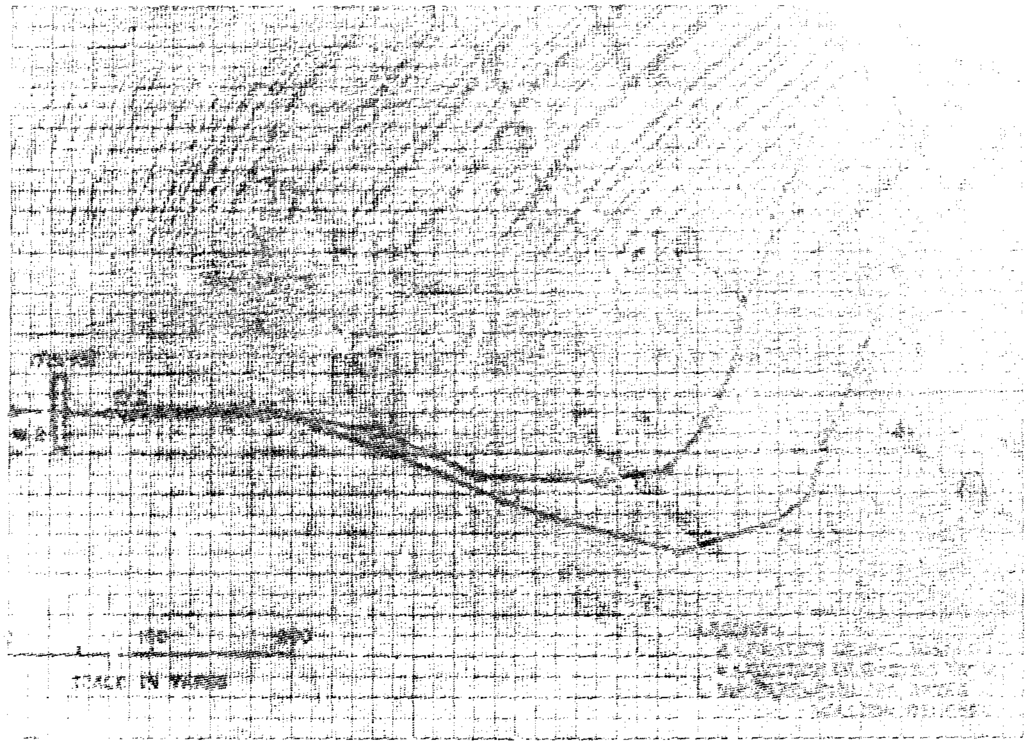
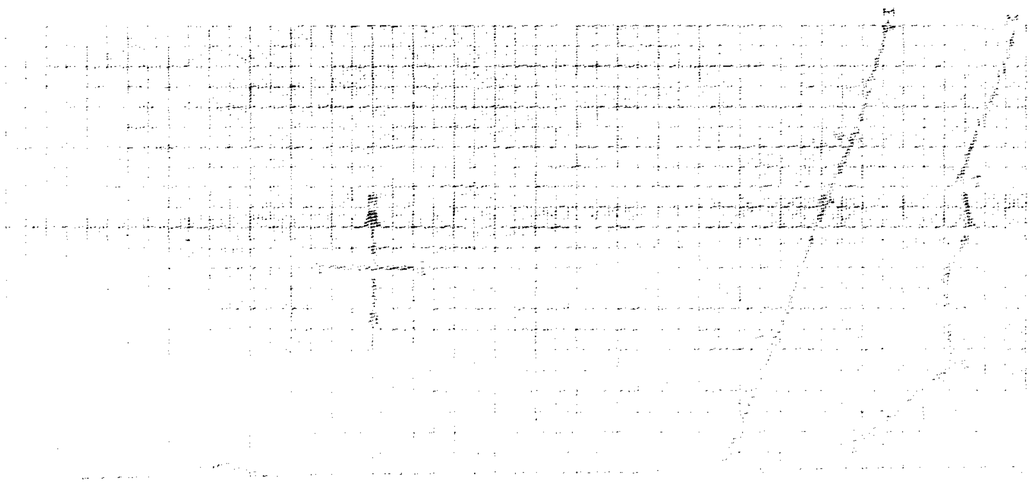


Fig. 27. Balloon trajectories.



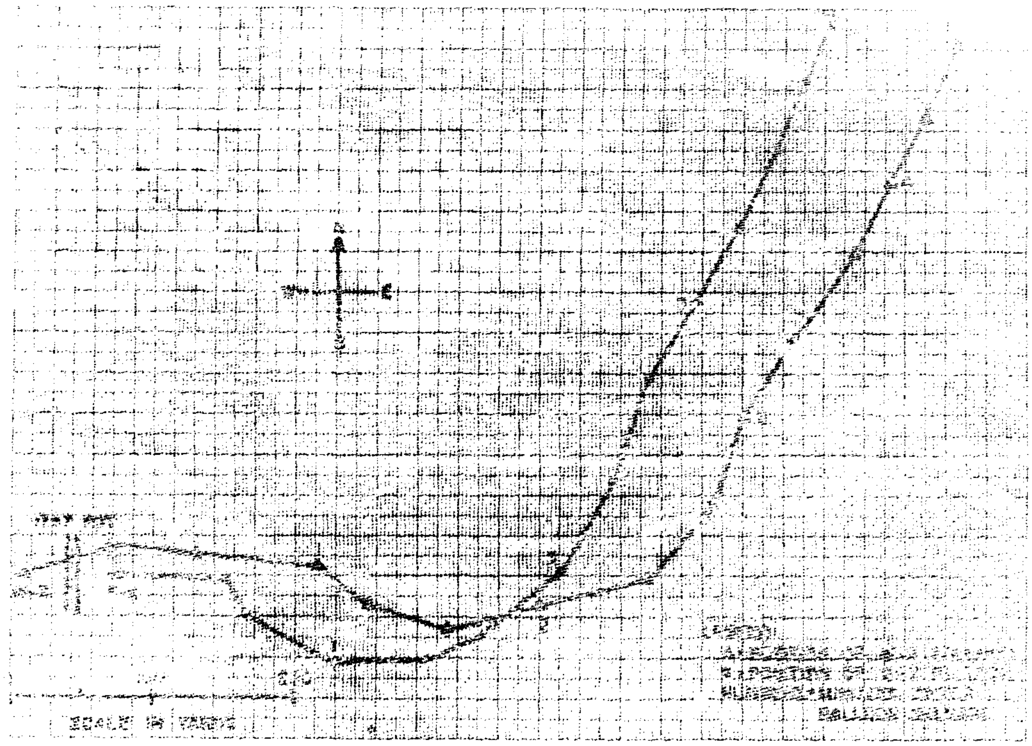


Fig. 29. Balloon trajectories.

Table 1. B & W WIND DATA - SHASTA - 11 Oct 57

	E-1				E-2				E-3			
TIME	AVG DIR	RANGE	AVG SPEED	RANGE	AVG DIR	RANGE	AVG SPEED	RANGE	AVG DIR	RANGE	AVG SPEED	RANGE
1610	200	180-225	3	2-4	240	170-275	3	2-4	(220)	Missing	3	2-4
15	185	175-200	3	2-4	220	150-250	3	1-4	(200)		3	2-4
20	210	195-230	2	1-3	215	0-360	2	0-4	(195)		3	1-5
25	225	205-245	3	1-6	260	170-350	3	2-6	255	205-300	4	2-7
30	240	195-290	2	1-5	290	195-340	4	2-6	260	210-290	4	2-7
35	215	155-310	3	1-6	280	15-360	3	0-7	265	195-300	4	2-8
40	190	60-310	5	2-8	255	20-360	4	1-6	245	200-290	6	3-10
45	(200)	Missing	6	4-9	270	45-360	4	1-8	240	210-275	6	2-9
50	(225)		14	3-17	230	65-325	9	1-16	205	20-360	7	2-13
55	(270)		18	13-20	235	195-260	14	8-17	(215)	Missing	9	1-16
1700	(270)		15	4-17	240	205-320	15	10-18	(220)		8	2-16
05	(270)		17	12-20	245	210-265	15	10-18	(225)		8	1-14
10	(250)		15	9-17	245	215-280	14	9-18	(225)		10	4-17
15	(240)		15	8-17	240	215-270	12	6-15	(220)		7	1-12
20	(225)		13	3-16	245	215-280	12	9-15	(225)		7	2-14
25	(225)		12	5-18	250	235-280	14	6-16	(230)		8	2-14
30	(235)		11	7-17	250	225-275	13	9-15	(230)		9	2-15
35	(210)	Missing	8	0-14	225	20-315	11	4-15	(205)		4	1-9
40	190	45-305	5	1-12	205	20-360	6	2-14	(185)		3	1-7
45	180	15-325	5	1-12	210	10-360	7	1-13	(190)		4	1-7
50	120	15-305	5	1-12	180	0-360	5	1-10	(160)		2	1-4
55	110	20-140	4	2-6	120	30-210	3	1-6	(110)		3	1-4
1800	105	60-135	4	3-6	135	60-170	4	2-6	(120)		3	1-4
05	[illegible]	35-135	5	2-7	145	55-190	4	1-6	(130)		3	1-5
10	60	15-115	5	2-7	115	65-160	3	1-6	(100)		2	1-3
15	70	35-105	5	3-7	110	70-145	4	2-6	(100)		2	1-3
20	90	65-110	4	3-6	130	90-170	3	2-5	(120)		2	1-4
25	155	15-325	4	2-5	185	20-270	4	2-8	(165)		3	1-5
30	145	15-325	4	2-9	220	0-360	5	0-9	(190)		2	1-3

E-1 75 ft. East of fire
E-2 125 ft. East of fire
E-3 175 ft. East of fire

Fire started 1640 PST 11 Oct 57
( ) - estimated data

Table 2. B & W WIND DATA - SHASTA - 11 Oct 57

	W-1				W-2				W-3			
TIME	AVG DIR	RANGE	AVG SPEED	RANGE	AVG DIR	RANGE	AVG SPEED	RANGE	AVG DIR	RANGE	AVG SPEED	RANGE
1610	235	225-250	3	2-4	235	215-260	3	2-4	260	220-305	4	2-5
15	230	205-275	2	2-3	235	205-260	3	2-4	255	205-285	3	2-4
20	220	180-250	2	2-3	225	185-260	2	2-4	250	215-290	3	1-5
25	245	220-270	3	2-3	245	210-265	4	2-6	270	230-310	4	2-6
30	255	230-275	3	2-4	255	225-270	3	1-5	275	230-310	3	2-5
35	245	200-270	3	2-5	250	215-265	4	2-7	265	205-305	4	2-7
40	230	205-265	3	2-4	235	210-265	5	3-7	250	195-290	5	3-8
45	225	205-255	4	2-5	230	205-255	5	3-8	250	215-275	5	3-8
50	235	215-260	4	2-6	235	210-265	6	4-9	260	200-285	6	4-9
55	245	200-275	5	2-6	250	205-280	6	4-10	275	240-320	6	3-9
1700	255	215-285	6	3-10	255	210-275	7	3-10	280	210-320	7	3-11
05	245	210-285	5	3-8	250	220-270	6	3-8	270	220-330	6	3-9
10	240	205-275	4	3-6	245	205-280	5	3-9	270	205-320	5	2-8
15	250	215-280	5	3-8	245	200-270	6	3-10	270	215-340	6	3-10
20	255	215-300	4	2-8	255	230-270	6	3-10	285	235-325	6	3-9
25	255	225-285	5	3-8	255	235-275	6	4-8	275	230-310	6	3-8
30	250	220-280	4	3-6	245	220-270	6	3-9	280	225-325	6	3-9
35	270	215-320	4	3-7	260	225-275	4	2-9	295	245-340	5	2-10
40	270	250-290	4	3-7	(260)	(230-275)	5	3-8	300	215-335	5	2-8
45	260	235-280	4	2-6	260	235-275	5	3-7	290	240-330	5	3-9
50	270	245-295	3	2-6	260	240-270	3	2-5	305	260-355	4	2-5
55	290	260-310	2	2-4	275	255-280	2	1-3	330	280-360	3	1-5
1800	295	275-305	2	1-3	275	275-280	2	1-3	325	310-340	3	2-4
05	310	385-320	2	1-3	285	280-290	3	2-4	355	315-360	3	2-4
10	280	250-315	2	1-3	280	250-320	3	2-4	305	260-360	3	2-4
15	270	240-305	3	1-4	270	250-275	3	2-4	300	260-335	3	2-4
20	245	225-265	2	2-2	260	235-270	2	1-2	275	235-310	2	1-3
25	255	235-270	2	1-3	255	235-265	3	2-4	285	250-305	3	2-4
30	275	265-285	3	2-4	270	265-275	4	2-5	305	275-330	4	2-6

W-1 75 ft West of fire
W-2 125 ft West of fire
W-3 175 ft West of fire

Fire started 1640 PST 11 Oct 57
( ) estimated data